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Prototype Evaluation of Bonneville Navigation Lock, Columbia River, Oregon

by Terry N. Waller

WES

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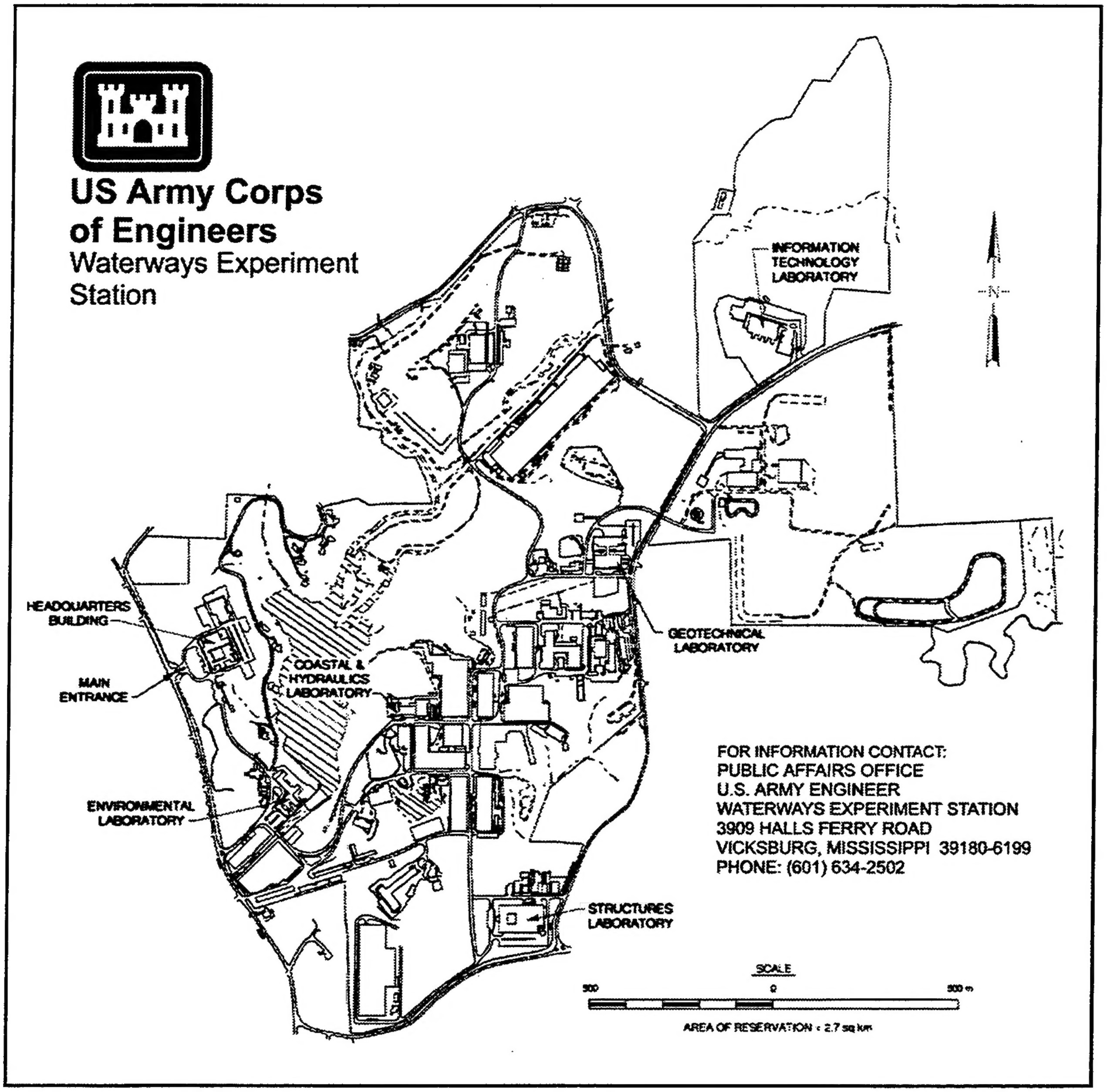

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Contents

Preface

A prototype evaluation of the Bonneville navigation lock was conducted by the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U.S. Army Engineer District, Portland. The field data collection was conducted in March and September, 1993.

The research was conducted under the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; G. A. Pickering, Chief of the Hydraulic Structures Division (HSD), HL; and Dr. B. J. Brown, Chief, Hydraulic Analysis Branch (HAB), HSD. Mr. T. N. Waller, HAB, was the principal investigator. Hydraulic consultation was provided by Dr. F. M. Neilson of the Hydraulic Engineering Analysis Center, HSD, and Mr. R. G. McGee, HAB. Instrumentation support was provided by Mr. S. W. Guy under the supervision of Mr. L. M. Duke, Chief of Operations Branch, Instrumentation Services Division, WES.

Messrs. Ted Edmister and Jim Stow of the Portland District were responsible for the hydraulic design of the navigation lock. They assisted in planning the prototype evaluation and coordinating the evaluation with project personnel. Acknowledgment is also made to the personnel of Bonneville Dam for their assistance in the investigation.

This report is being published by the WES Coastal and Hydraulics Laboratory (CHL). The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL, and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors.

During the preparation of this report, Dr. Robert W. Whalin was Director of WES, and COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
degrees Fahrenheit	5/9	degrees Celsius or kelvins[1]
feet	0.3048	meters
inches	25.4	millimeters
miles (U.S. statute)	1.609347	kilometers
pounds (force) per square inch absolute	6,894.757	pascals
square feet	0.09290304	square meters

[1] To obtain Celsius © temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

1 Introduction

The Prototype

The Bonneville Project is located on the Columbia River at the head of tidewater, 146 miles[1] above the mouth and 42 miles east of Portland, OR (Figure 1). The new navigation lock was constructed adjacent to the south side of the existing lock along the Oregon shoreline. The lock coordinates at station 30+00 are N 721,645.00, E 1,629,535.00, with stationing increasing along the lock center line in the downstream direction.

Description of Structures

The principal structures at the Bonneville Project consist of a spillway dam, an existing navigation lock, the first powerhouse, the second powerhouse, and the new navigation lock.

a. *Spillway dam*. The concrete gravity dam has an ogee crest and is gate controlled. The overall length of the dam is 1,450 ft. Closure of the dam was conducted in September 1937.

b. *Old lock*. The old lock, which began service in January 1938, has chamber dimensions of 76 ft wide by 500 ft long. The lock filling and emptying system consists of a 14-ft-diameter longitudinal main culvert and 41 4-ft-diameter filling and emptying ports.

c. *First powerhouse*. The first powerhouse is 1,027 ft long by 190 ft wide. It includes 10 hydro-generating units that result in a total rated capacity of 518,400 kW. Installation of all 10 units was completed in December 1943.

d. *Second powerhouse*. Installation of the second powerhouse was completed in October 1982. This powerhouse has a length of 985.5 ft and a width of 221.25 ft and has a total rated capacity of 558 MW.

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[1] A table of factors for converting non-SI units of measure to SI units is found on page vi.

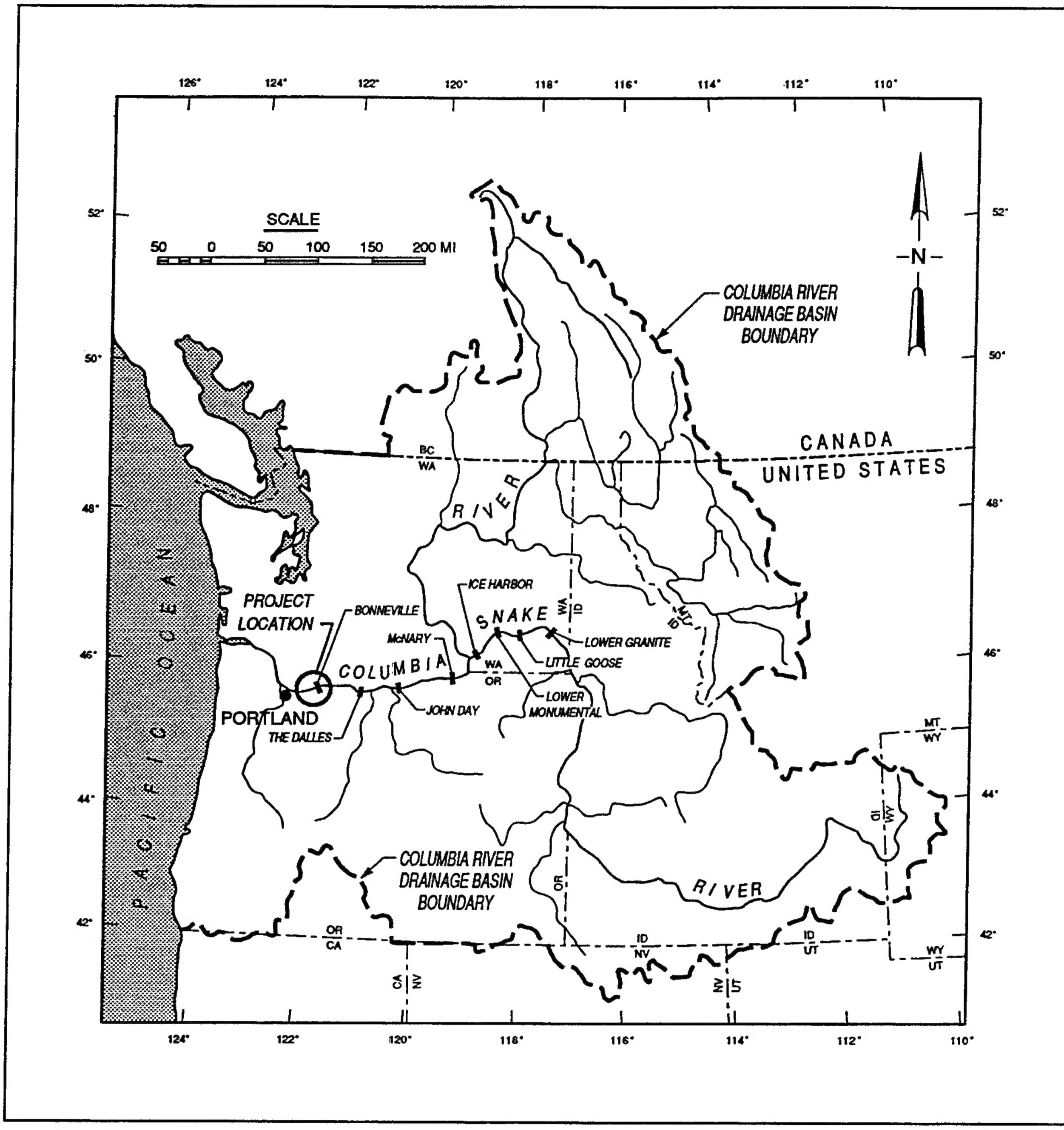

Figure 1. Vicinity map

e. New lock. The new lock has chamber dimensions of 86 ft wide by 675 ft long. The upstream and downstream guide walls are 940 and 950 ft in length, respectively. The upper sill has a top elevation of 51[1] and the lower sill has a top elevation of -12. The project has a design draft for loaded vessels of 14 ft. The new lock was opened in March 1993.

[1] All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Lock Design

The Bonneville Project can have a normal pool fluctuation between el 71.5 and el 76.5. The pool has been operated at an elevation as high as el 82.5 and as low as el 70.0. Elevation 76.5 was established as the design pool for the new lock model studies. Since Bonneville is the lowermost dam on the Columbia River, a wide range of tailwater can be expected. A minimum tailwater of el 7.0 was used for design, but since degradation of the downstream channel may occur, lower tailwater elevations were also evaluated. A combination of pool el 76.5 and tailwater el 7.0 resulted in a design lift of 69.5 ft.

Purpose and Scope of the Study

Purpose

The primary purposes of the prototype evaluation were to (a) determine the operating characteristics and hydraulic efficiency of the lock, (b) evaluate the accuracy of both physical and analytical model predictions, and (c) evaluate important design factors such as the cavitation parameter and the effects of submergence. Determinations of prototype discharge and loss coefficients for the culverts and valves were secondary objectives.

Scope

Two separate sets of prototype data were collected at Bonneville Lock. The first set of experiments was conducted in March 1993, immediately after completion of the lock and prior to initial lockages. All available instrumentation was used during this set of experiments. A second set of experiments was conducted in September 1993 during conditions of low tailwater. Pressures were measured only at potential locations of extreme low pressure during this set of experiments.

The conditions evaluated were (a) normal filling and emptying and (b) valve operations to determine incipient cavitation and effects of submergence. Individual experiments of these types varied with respect to the valve times and single- or dual-valve operations.

Prior model studies

Previous model studies of the lock have been conducted by the U.S. Army Engineer Waterways Experiment Station (WES). Experiments were conducted on two different 1:25-scale models reproducing the entire filling and emptying system (Stockstill and George 1996). The first design studied consisted of four longitudinal floor culverts in each end of the lock chamber. The second design had two

longitudinal floor culverts in each end of the lock chamber. The second system was the system constructed and evaluated.

2 Measurements, Equipment, and Procedures

Measurements and Equipment

Locations of the lock instrumentation are shown in Plates 1 and 2. The specifics of each pressure transducer are listed in Table 1. A detailed description of the complete set of instrumentation (50 channels) used in the March experiments follows. During the September series of experiments, 11 channels of data were recorded. These channels were generally in areas of low pressure, as noted in Table 1.

Facilities for 34 flush-mounted pressure transducers were installed during construction in the filling and emptying culverts of the Bonneville Lock at the locations shown in Plate 1. These consisted of an embedded transducer mounting box and a 2-in. conduit for cable passage with a pull wire extending to either the upper deck of the lock or the ladder wells at the lock floor level. Two 6-1/2-in.-diameter, 3/8-in.-thick interchangeable cover plates were fabricated for each mounting box, one for permanent cover and one to be used by WES to install the pressure transducers prior to the initial lock waterup.

In addition to the flush-mounted pressure transducers, transducers were installed in each valve well prior to waterup. Before data collection began, pressure transducers were installed in four of the ladder wells to measure the water surface in the lock chamber. Additional transducers were installed to monitor upstream and downstream stages. Potentiometers and switches were installed to monitor miter gate and tainter valve movement.

Valve liner roof pressures (FE-1 to FE-4)

A flush-mounted pressure transducer was installed in the roof of the steel liner downstream of each of the four reverse tainter valves. These transducers were to measure the average and fluctuating pressures in the highly turbulent flow immediately downstream of the tainter valves.

Culvert roof pressures (LT-1 to LT-8)

Three flush-mounted pressure transducers were located in the top of each filling culvert. Pressures were also measured at one location in each emptying culvert. These transducers were used to evaluate pressure fluctuations downstream of the tainter valves. The transducers were also used to determine the balance between the sides of the lock filling and emptying system.

Crossover area (FS-1 to FS-6 and FE-5 to FE-8)

On each side of the lock a pressure transducer was mounted on the nose of the horizontal splitter along with a transducer on top and bottom of the splitter. This arrangement was used to evaluate the flow balance in the top and bottom halves of the culvert. The system was also used as a pitot tube type arrangement to determine culvert velocities on some experiments. Additional pressure transducers were mounted at midheight at the 45-degree point on the inside of each of the curved bends in the crossover area in an area of low pressures.

Floor manifold (FM-1 to FM-8)

Pressure transducers were mounted in the ceiling of the floor manifolds. On each of the four manifolds a transducer was located at the outer end of each manifold and also near the crossover area. These manifolds were compared with each other in order to help determine the balance of flow in each quarter of the lock.

Empty system manifolds (EM-1 to EM-4)

Pressure transducers were mounted in the ceiling of the emptying manifolds. A transducer was located near each end of each transverse emptying manifold. These transducers were used to help determine the balance between the two emptying culverts.

Valve well water surface (WSFL, WSFR, WSEL, WSER)

A pressure transducer was mounted on the valve well wall above the tainter valve supports in each of the valve wells. These transducers were located to determine the water surface drawdown in each of the valve wells during filling and emptying.

Lock water-surface elevation (LWR-1, LWR-3, LWR-4, LWL-3)

The lock water-surface elevation was measured continually for each experiment with four pressure transducers. The transducers were mounted in a pipe adapter and rigidly attached to ladder rungs in the ladder wells. One transducer was mounted in

the center left side ladder well. Three more transducers were mounted in the right side ladder wells. The transducers were mounted several feet below the minimum expected tailwater.

Valve opening (VEL, VER, VFL, VFR)

Movement of any operating tainter valve (filling or emptying) was monitored for the duration of each experiment. The measuring devices were linear potentiometers. Each potentiometer was attached to an indicating rod whose movement was parallel to the movement of the piston that operated the tainter valve machinery. The actual opening of the tainter valve was calculated based on the geometry of the tainter valve machinery.

Upstream water surface (WUS)

A 15-psia pressure transducer was mounted on the right side upstream bulkhead slot. The transducer elevation was about 2.5 ft below the average upstream water surface. Additionally a differential pressure transducer with a data logger was placed in the forebay to log the upstream water surface at 1-minute intervals for the duration of the March data collection.

Downstream water surface (WDS1, WDS2)

A 15-psia pressure transducer was mounted on the downstream side of the right downstream miter gate. A second transducer was suspended in the downstream bulkhead slot. A differential pressure transducer with a data logger monitored the tailwater at 1-minute intervals during the March data collection.

Miter gate opening (USM, DSM)

Movement of the miter gates caused by overfilling (upstream gates) or overemptying (downstream gates) was monitored to obtain the time initial gate opening occurred. Microswitches were mounted on the mating edges of each pair of upstream (USM) and downstream (DSM) miter gates to record the time of initial gate opening.

Equipment Installation and Recording Equipment

Each pressure transducer was wired, placed in a waterproof brass housing and calibrated at WES. Transducer cables were cut long enough to reach the upper deck of the lock. The cable lengths were determined from contract drawings and actual measurements at the project. The transducer assemblies were checked for leaks and then calibrated using a deadweight calibration apparatus. The transducer was calibrated to an accuracy of 0.1 percent of full scale. The transducer and cable

assemblies were installed in the lock prior to waterup. The cables were routed to either boxes on the lock decks or through ladder wells to the lock deck. Immediately prior to data collection, additional cable lengths were added to connect the transducers to the data acquisition system. Each transducer calibration was adjusted to account for the additional cable length.

The recording equipment was housed in an instrumentation van parked on the north side of the lock. Cables were routed to the van through galleys, along the lock wall, and across the lock chamber. The recording equipment included filters and WES-fabricated bridge amplifiers to condition the transducer signals. Additional equipment provided calibration voltages and interfaces. The primary data logging equipment was a 64-channel analog-to-digital card in a 486 computer with 20 megabytes of RAM. The computer was capable of recording all 50 data channels for the entire filling or emptying cycle of the lock at a logging rate of 50 samples per second. Selected channels could be recorded at rates up to 500 samples per second. A 32-channel analog tape recorder was also used to record selected data during each experiment.

Data Collection Procedure and Conditions

Filling and emptying experiments

These experiments were concerned primarily with the overall performance of the lock during filling and emptying operations. During these experiments the chamber was being either filled or emptied and the data recorded continuously during the entire locking operation. Two general types of filling and emptying experiments were conducted: (a) allow the chamber pool to overfill or overempty to the maximum, and (b) minimize the overtravel (normal operations). To allow maximum overtravel, the valves were held fully open throughout the entire operation. Normally, to minimize overtravel, when the chamber elevation neared that of the upper pool, the valves were lowered. At the time of data collection, no standard procedure had been established to minimize overtravel.

Variables

Specific information about each experiment is listed in Table 2. For the filling and emptying experiments, the valves were the lock components that were controlled. Three nominal valve times were used for filling experiments: 1 minute, 2 minute, and 4 minute. In addition, both normal two-valve and single-valve operations were performed.

Conditions

Upper pool, chamber, and lower pool elevations were observed visually from staff gauges before and after experiments. These readings were used to correlate

preexperiment and postexperiment pressure transducer data readings to elevations. These data and brief descriptions of the conditions during each run are listed in Table 2.

Recording Procedures

Individual experiments were recorded on a 486 computer using the analog-to-digital card at a digitizing rate of 50 samples per second. The data were also recorded on magnetic tape for the duration of filling or emptying. The recording procedure was generally the same for all experiments and consisted of the following:

a. Set and read initial experiment conditions such as pool elevations and valve operation (logged on data sheets).

b. Record pretest zero levels.

c. Record transducer step calibrations.

d. Record initial static conditions.

e. Record data.

f. Record final static conditions.

g. Record postexperiment transducer calibrations.

h. Record postexperiment zero levels.

i. Prepare for next experiment.

Voice comments on the tape and notes on the data sheets were continuously made for later reference. Calibration changes were made as required during the evaluation period.

Analysis Procedures

The data reduction and analysis were performed by WES personnel. All data channels were recorded simultaneously to provide a direct time-dependent relationship among all channels. The data reduction included decimating the digitized data, fine-tuning the preexperiment transducer calibrations, and performing all appropriate analyses needed to present the results in the desired form. During this process the data from the pressure transducers were converted to piezometric head in ft NGVD or elevation in ft NGVD. Unless otherwise noted, all data from pressure transducers are in ft NGVD.

3 Basic Lock Performance

Lock Performance Parameters

General lock performance was evaluated by a sequence of various filling and emptying procedures. These experiments include the six basic types of valve operations: normal filling and emptying (two synchronized valves) and left and right side single-valve filling and emptying operations. Plate 3 is a definition sketch showing the important parameters measured for evaluating lock performance.

During filling and emptying runs, the valve movement is initiated at time $t = 0$ and reaches fully open at time $t = t_v$. The initial differential head H is the difference between the upper and lower pools, i.e., $H = Z_U - Z_L$. The rate of rise of the water surface dz/dt increases from time zero to a maximum at time t_m, after which it decreases continually, reaching zero at time t_f. The operation time, or filling (emptying) time, is designated as T. The inertia of the water in the filling system causes the water surface to rise above the upper pool after time T. This overtravel (or overfill) is defined as the distance d_f and occurs at time t_f. During emptying, the overtravel (or overempty) extends below the lower pool the distance d_e at time t_e.

Valve Operation

Valve movement was measured by transducers VFL, VFR, VEL, and VER previously described. The valves were operated by the vertical movement of a hydraulic piston. Any movement of the hydraulic piston was measured by the potentiometers on the indicator rod. This relative motion measurement was converted to actual valve position, b, where b is the opening height in feet above the invert culvert, by a relationship based on the geometry of the valve and valve linkage. Plate 4 presents this valve opening calibration in terms of percent valve opening b/B, where B is the maximum valve opening (14 ft) versus percent of valve time. Also shown is the predicted valve opening schedule used in the physical model. All valves were assumed to be identical. Plate 2 is a diagram of the reverse tainter valves and machinery.

For filling and emptying experiments, the nominal rates were 1, 2, and 4 minutes. The 1-minute rate is the normal operating condition. Actual valve operation

times for each experiment are given in Table 2. Plates 5 to 18 show the measured valve patterns for selected filling and emptying operations. For the two-valve operations, the valves acted in synchronization.

Operation times

Operation times for filling and emptying the lock are listed in Table 2. Selected filling and emptying curves are shown in Plates 5 to 18. The lock water surface for most experiments was allowed to overtravel for the purpose of determining the full operation times required by the filling and emptying system. After a complete series of experiments was run, the lock overtravel was restricted in many cases by partially closing the tainter valves. This resulted in longer filling times. For these experiments, the change in the lock water surface dz/dt was plotted against time. The best-fit line was determined for the period from when the tainter valve was fully open until the tainter valve began closing. The best-fit line was integrated and evaluated at a time having a known water surface. This resulted in an equation defining the lock filling curve. This equation was then used to extrapolate the lock filling time and the amount and time of maximum overtravel.

Overtravel

Most experiments were performed to permit overtravel. This required maintaining the valves fully open during the entire operation and keeping the appropriate miter gates closed. The miter gates were designed to open under reverse head. The time at which the miter gates opened is noted under the column, "Miter Gate Opening Time" in Table 2. The measured overtravel may be somewhat less than what would be expected had the gates been held closed throughout the entire operation. Table 2 lists the measured or extrapolated amount of overtravel (d_f or d_e) and the time when it occurred for each experiment.

Culvert Discharge Coefficient

The discharge coefficient C of the hydraulic system is based on the equality of the rate of rise of the lock chamber water surface and the rate of flow through the culvert(s). It is determined as

a. Filling:

$$C = \frac{A_L \dfrac{dz}{dt}}{A_c' \sqrt{2g(Z_U - z)}} \tag{1}$$

b. Emptying:

$$C = \frac{-A_L \dfrac{dz}{dt}}{A_c' \sqrt{2g(z - Z_L)}} \qquad (2)$$

where

A_L = water-surface area of the lock chamber, ft^2

A_c' = representative cross-sectional area of the culvert(s), ft^2

g = acceleration due to gravity, ft/sec^2

z = elevation of water surface in the lock chamber, ft

The rate of rise of the water surface dz/dt reaches a maximum soon after the tainter valve reaches its open position. The best-fit line of the change in the lock water surface dz/dt was used to determine values for dz/dt at several times near the maximum fill rate. The lock water surface was also determined at these times. The representative culvert cross section area used was that in the valve liner area (168 sq ft). The lock area used was 62,000 sq ft for filling and 62,800 sq ft for emptying. These values for A_L were scaled from the construction drawings. The calculated culvert coefficients were averaged for each experiment and are listed in Table 3. Average values of C for the normal two-valve and single-valve filling runs are 0.72 and 0.83, respectively. The emptying values are 0.57 and 0.61, respectively for the normal and single-valve operations.

Valve coefficients

Operation times are shown in Plate 19 for filling and emptying runs from the March and September series of experiments. Prototype emptying runs are presented, but the effects of the tailwater rising over the outlets are unknown. The valve coefficient k is the slope of the curves in Plate 19. These curves can be extrapolated to determine the lock operation time if the valve movement is instantaneous. On filling experiments $k = 0.55$ and on emptying tests $k = 0.50$. These values are used in the calculation of the lock coefficients.

Lock design equation

A relationship between operation time, lock chamber area, and total lift is required for lock design. This relationship is expressed by the traditional empirical lock design equation (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 1995) or Pillsbury's equation

$$T - kt_v = \frac{2A_L}{\sqrt{2g}\ C_L A_c'} \left(\sqrt{H + d_o} - \sqrt{d_o}\right) \tag{3}$$

where

k = overall valve coefficient

C_L = overall lock coefficient (comparable to the culvert coefficient C of Equations 1 and 2)

d_o = overtravel, ft

Equation 3 is based on a solution for lock filling in which inertial effects are accommodated by incorporating overtravel into the final solution. The equation applies to both filling and emptying runs, provided d_f or d_e is properly substituted for d_o. The lock design equation was used for the experimental determination of C_L and for comparison of model and prototype efficiencies. Using an average value, 62,600 sq ft, for A_L and nominal design values of 0.55 for filling and 0.50 for emptying for k, values of the overall lock coefficient are listed in Table 3. Average values of C_L for the normal and single-valve filling runs are 0.71 and 0.82, respectively. The emptying values are 0.57 and 0.62, respectively, for the normal and single-valve operations. Culvert coefficients for filling and emptying are not significantly greater.

Overall loss coefficient

Basically, the overall head loss H_L in the Bonneville lock filling system is considered to be made up of five separate components as described in Equations 4-8, listed in the following tabulation.

Component	Loss Location	Head Loss	Equation
Intake manifold	Upper pool to the upstream valve well	$H_{L1} = \frac{k_1 V_c^2}{2g}$	(4)
Valve and culvert transition	From valve well to circular culvert section	$H_{LV} = \frac{k_v V_c^2}{2g}$	(5)
Filling culvert	Upper to lower end of filling culvert	$H_{L2} = \frac{k_2 V_c^2}{2g}$	(6)
Crossover system	Lower end of circular conduit through horizontal splitter to floor manifold	$H_{L3} = \frac{k_3 V_c^2}{2g}$	(7)
Floor manifold (outlet)	From floor manifold to lock chamber	$H_{L4} = \frac{k_4 V_c^2}{2g}$	(8)

The overall loss, H_{Lt}, is

$$H_{Lt} = (k_1 + k_v + k_2 + k_3 + k_4) \frac{V_c^2}{2g} \tag{9}$$

or

$$H_{Lt} = \frac{k_t V_c^2}{2g} \tag{10}$$

where k_t is the overall loss coefficient and V_c is the average velocity of flow in the culvert. In practice, coefficients k_1, k_v, k_3, and k_4 are taken to be entirely form dependent. The culvert loss (coefficient k_2) is affected by both form and relative roughness. However, in a lock system, form losses dominate and k_2 can reasonably be assumed constant for either model or prototype. All of the loss coefficients are affected by Reynold's number; therefore, significant differences will exist between the model and prototype values.

Losses occur in similar locations in the emptying system and are described in the following tabulation. The same equations are used in the emptying system in a slightly different order.

Component	Head Loss Location	Head Loss	Equation
Intake manifold	Lock chamber to floor manifold	$H_{L1} = \dfrac{k_1 V_c^2}{2g}$	(4)
Crossover system and circular empty culvert	Floor manifold to downstream valve well	$H_{L2} = \dfrac{k_2 V_c^2}{2g}$	(6)
Valve	From valve well to downstream culvert	$H_{LV} = \dfrac{k_v V_c^2}{2g}$	(5)
Culvert and bendway	Empty culvert to empty manifold	$H_{L3} = \dfrac{k_3 V_c^2}{2g}$	(7)
Empty manifold	From empty manifold to downstream pool	$H_{L4} = \dfrac{k_4 V_c^2}{2g}$	(8)

The overall loss, H_L, is the sum of the individual losses. In the emptying system the loss coefficients are all primarily form dependent. As with the filling system, significant differences will exist between the model and prototype values.

A brief description of the equations used to describe the unsteady lock flow follows. The flow is assumed incompressible and the inertial effect is treated as a lumped quantity; that is,

$$H_m = \frac{L_m}{g} \frac{dV}{dt} \tag{11}$$

where

H_m = overall inertial head

L_m = equivalent length (inertial)

$$L_m = A_{cb}^{/} \sum_{i=1}^{m} \frac{L_i}{A_i} \tag{12}$$

for a conduit made up of m sections of lengths L_i and areas A_i.

The water-surface differential $Z_U - z$ is the sum of the inertial effect (Equation 11) and the energy losses (Equation 10), or

$$\frac{k_t V_c^2}{2g} = (Z_U - z) - \frac{L_m}{g}\frac{dV}{dt} \tag{13}$$

At a given time, continuity applies to the culvert flow and the rate of rise of the lock chamber water surface giving

$$V_c\,(nA_c^{/}) = \frac{A_L}{nA_c^{/}}\frac{dz}{dt} \tag{14}$$

where

n = number of culverts

and

$$\frac{dV_c}{dt} = \frac{A_L}{nA_c^{/}}\frac{d^2z}{dt^2} \tag{15}$$

From Equation 13 the head loss due to inertia becomes zero when dV/dt is zero. The value of dV/dt becomes zero when the filling or emptying discharge is at its maximum and the rate of rise (fall) of the lock water surface is at its maximum. This time occurs near the time at which the tainter valve becomes fully open. If the discharge and difference between the upper and lower pool are known, then k_t can be calculated directly from Equation 13. Similarly, the individual losses k_1 through k_4 and k_v can be calculated using the total head differences between appropriate locations in the system. These equations relate primarily to lock filling; however, they also apply to emptying, provided appropriate sign changes are applied. Calculated values for filling system losses are shown in the following tabulation.

Experiment Condition	Experiment Number	V_c fps	k_1	k_v	k_2	k_3	k_4	k_t
Dual fill	2	38.4	0.20	0.13	0.14	0.36	1.12	1.95
	15	35.4	0.21	0.12	0.12	0.34	1.12	1.91
	18	29.0	0.25	0.12	0.11	0.35	1.12	1.95
Single fill, right side	6	46.1	0.07	0.19	0.17	0.77	0.27	1.47
Single fill, left side	10	46.2	0.07	0.18	0.16	0.79	0.26	1.46

Losses for the emptying system are included in the following tabulation. Due to the location of the pressure transducers, k_3 and k_4 are combined into k_3.

Experiment Condition	Experiment Number	V_c fps	k_1	k_2	k_v	k_3	kt
Dual empty	4	30.5	0.38	1.23	0.29	1.28	3.18
Single empty, right side	8	35.4	0.08	0.98	0.25	1.27	2.58
Single empty, left side	11	34.1	0.09	1.00	0.32	1.32	2.73

The total loss coefficient was determined using Equation 13 on additional experiments. Although not as detailed an analysis, the method was especially useful on the September series of experiments. Those experiments had a higher head, but too few pressure locations were logged to determine individual loss coefficients. The method requires knowing the total head loss at the maximum rate of rise of the lock water surface. This maximum rate of rise is near time t_v, but fluctuations in the data could cause errors. These data are shown in Table 4. The average values of k_t determined from this method are 1.93 for the dual-valve fill, 1.46 for the single-valve fill, 3.09 for the dual-valve empty, and 2.66 for the single-valve empty. Differences between the coefficients for the March and September experiments were insignificant.

Model-prototype correlation of basic lock performance

A convenient comparison of the relative efficiencies of the model and the prototype is by means of the lock design equation (Equation 3) solving for C_L. The ideal model-prototype comparison would include the exact duplication of all lock operation variables, i.e., pool elevations and valve times. These varied from the physical model to the prototype. However, as shown in Tables 3 and 4, there were only small changes in C_L and k_t from March to September when the heads and valve times changed significantly. It was determined that comparing the averaged prototype values to the design head values from the model would be acceptable. The model values of C_L and the estimated prototype values were calculated using model data and provided to the district by Neilson.[1,2]

The results are compared in Table 5. As shown in this table, the prototype fills and empties more efficiently than the model. The completed lock is also more efficient than the estimates of the prototype. The differences in the comparative efficiencies for the various conditions are expected at Bonneville due to the combined

1 Frank Neilson. 14 July 1988. Memorandum for Record, CEWES-HS-H, Subject: Prototype Performance; New Bonneville Lock.

2 Frank Neilson. October 1988. Memorandum for Record, CEWES-HS-H, Subject: Prototype Performance; New Bonneville Lock.

effects of duration of lock operation (single-valve runs are longer) and the large difference in Reynold's number R between the model and prototype.

Included in Table 5 is the comparison of the model and predicted prototype values of k_t. The prototype k_t values are from the computations previously described. For the model and predicated prototype values

$$k_t = \frac{1}{C_L^2} \tag{16}$$

This relationship is a valid approximation of the loss coefficient.

Plates 20 to 23 compare the prototype measured values for lock chamber water-surface elevation with values for the numerical model, H5322 (Neilson and Hebler 1988). The conditions presented are for dual- and single-valve filling and emptying at the nominal 1-minute valve rate. The numerical model was calibrated to the prototype according to the actual head and valve operation time from the September experiments. As shown, H5322 calculates the filling curve very accurately. The average difference between the measured and calculated water surface on the filling experiments and the dual-valve emptying experiment was less than 1 ft. The average difference for the single-valve emptying experiment was 2.3 ft. These comparisons show that in most cases the numerical model is very accurate.

4 Hydraulic Characteristics of the Culverts and Valves

Culvert Pressures Downstream from Valves

Piezometric pressures were measured downstream of the filling and emptying valves. These pressure cells were in the valve liner plate near the point of minimum pressure. These locations are denoted as FE-1 and FE-4 for filling valves and FE-2 and FE-3 for the emptying valves. Plates 1 and 2 show actual locations and Table 1 lists specifics about the transducers. Plates 5 to 18 present the averaged pressures for typical filling and emptying runs. Table 6 (March) and Table 7 (September) lists the minimum, maximum, and mean low pressures over the 10-second period bracketing the mean low pressure for the nondecimated data. The time of the pressures relative to the start of tainter valve movement is also listed as well as the peak-to-peak pressures and the standard deviation of pressure in the time period.

Additional pressure cells (LT-1, LT-8) were also located in each culvert 49 ft downstream of the filling valve pressure cell. These pressure cells were downstream of the transition from the rectangular section at the valve liner to the circular conduit.

Typical culvert pressure time-histories from data collected at 50 samples per second are shown in Plates 24 and 25. These time-histories give a good indication of the magnitude and intensity of the pressure fluctuations occurring at these locations. The mean piezometric pressure at FE-1 and FE-4 fell below that of LT-1 and LT-8, respectively, during valve operation and then stayed slightly higher after the valve reached fully open. However, the pressure fluctuations were more intense for the downstream locations. These higher fluctuations were caused most likely by the turbulence created by the bulkhead recess and the transition zone. Noisy conditions were noted under certain conditions in the area around the bulkhead slot.

Plates 20 and 21 present the numerical model-prototype comparison of the mean piezometric pressures acting on the culvert roof at transducer location FE-1 for the September experiments 2-12 and 2-13. The tests were dual- and single-valve operations. Comparison of H5322 with the prototype for the 1-minute valve operation revealed differences of less than 3 ft in minimum pressures. Plates 22 and 23 present the numerical model to prototype comparison at the pressure transducer

FE-2 below the empty valve for September experiments 2-14 and 2-17. These tests were dual- and single-valve emptying operations. The predicted minimum pressure and the measured pressure differed by less than 1 ft for the two-valve operation and by 4.5 ft for the single-valve operation.

Valve Well Water-Surface Elevations

Valve well water-surface elevations were monitored in all valve wells. Filling and emptying valve well measurements are shown in Plates 5 to 13 for the March tests. The valve wells functioned as piezometers with the water-surface elevations providing a convenient measure of the piezometric heads at the valves. Table 6 (March series) lists the minimum, maximum, and mean low pressures over the 10 second period bracketing the mean low water-surface elevation.

Crossover Area

Low pressures were also monitored in the bends of the crossover area. Tables 6 and 7 contain these data for 10 seconds around the minimum value. The instantaneous minimum piezometric elevations for the March tests were 9.0 ft for a two-valve fill test and -14.7 ft for a single-valve filling operation. The September set of experiments showed pressures below atmospheric under certain conditions. The minimum two-valve fill experiment elevation was 0.2 (Experiment 2-3) and the minimum single-valve fill elevation was -28.4 (Experiment 2-13) on pressure transducer FE-5. This piezometric pressure is 8.3 ft below the pressure transducer elevation of -20.1 and 11.4 below the roof elevation of -17. The mean minimum value during this condition was -23.4 ft. Engineering Manual 1110-2-1602, paragraph 2-16, states that minimum average local pressures of -20 ft of water can be expected to be cavitation free in areas of gentle transitions (HQUSACE 1980). However, in highly turbulent areas such as gate slots, minimum average pressures should not be less than -10 ft of water. Experiment 2-16 was conducted using a stepped valve pattern, and the minimum piezometric pressure was -12.6 ft, which is 7.5 ft above the pressure transducer and 4.4 ft above the roof elevation. Plates 26 and 27 show the piezometric pressures at transducer FE-5 for Experiments 2-13 and 2-16, respectively. Since the usual single-valve fill operation uses a stepped valve, no problems should be encountered in the crossover area.

Cavitation Index

McGee (1989) used field experiments at Bay Springs Lock to determine the value of the cavitation parameter σ at the point of incipient cavitation of unvented reverse tainter valves. At Bay Springs Lock the probability of cavitation increased as σ dropped below 0.6. The data reduction process determines values calculated from field measurements and observations. The analytical relationships are as follows:

Roof pressure $(p/\gamma_w)_r$ (feet above culvert roof) is calculated as

$$\left(\frac{p}{\gamma_w}\right)_r = H - Z_r - \left(\frac{1}{2g}\right)(V_c B/C_c b)^2 \tag{17}$$

where Z_r is the culvert roof elevation in feet. The contraction coefficient C_c is dependent on the tainter valve opening. The cavitation parameter is calculated from

$$\sigma = \frac{\left(\frac{p}{\gamma_w}\right)_r + 33.0 + (B - C_c\, b)}{(V_c\, B/C_c\, b)^2/2g} \tag{18}$$

where the value -33.0 ft is assumed as vapor pressure (water at 70 °F).

The cavitation parameter was calculated near the time of minimum pressure downstream of the tainter valves. Equation 17 was used to calculate C_c at the time of the pressure in question. Equation 18 was then used to calculate the cavitation parameter. Field observations and calculated values of C_c and σ are included in Table 8. Values from Experiments 2, 6, and 25 from the March series are shown. Cavitation parameters from the September Experiments 2-12, 2-13, 2-14, and 2-17 are included. The only experiments in which a major cavitation boom occurred was Experiment 25 from the March series when the tainter valve was shut during the filling operation. Experiment 2-12, a normal fill experiment, showed no indications of cavitation. Experiment 2-13, a single-valve fill experiment, was analyzed at several valve positions and did show cavitation potential. Experiment 2-17, a single-valve empty experiment, also showed cavitation potential. Significant noise or airflow did occur in the valve well during single-valve filling or emptying experiments.

Balance of Flow During Filling and Emptying

The pressures in the lock filling culverts and floor manifolds were compared to determine any possible flow variations in the different quarters of the lock. Pressures were evaluated for a 30-second period after the tainter valves were fully opened. Experiment 2 (1-minute valve time) and 15 (4-minute valve time) were fully evaluated. All transducers on the filling side of the lock were examined for minimum, maximum, and mean values along with peak to peak values and standard deviations. The values for the culverts are plotted in Plate 28 and shown in Table 9.

The values for piezometric pressures in the floor manifold are plotted in Plate 29 and are shown in Table 10. Pressure values for opposite sides of the locks are very similar. Right side filling (Experiment 6) and left side filling (Experiment 10) results are plotted in Plate 30. Maximum, minimum, and mean pressures for the two tests seemed to mirror each other as expected.

The flow balance in the emptying manifold was evaluated using pressure values over a 10-second period at the time of maximum pressure. The piezometric pressures are tabulated in Table 11. The pressures in these manifolds were also very symmetrical.

5 Conclusions and Recommendations

Lock Operation

The prototype tests confirmed that New Bonneville Lock functioned as designed during normal filling and emptying operations. The tests did not indicate any potential for major problems. The study can be used as a guide for future operation of the lock. The prototype tests indicate that there should be no operational problems at the Bonneville lock during normal valve operations. The stepped valve operation should be used for single-valve filling and emptying operations especially during periods of low tailwater. This operation will eliminate the potential for cavitation at the tainter valves and in the crossover region.

Overall Lock Coefficient

The lock coefficients for dual-valve prototype operations were found to be 0.71 for filling and 0.57 for emptying. The lock coefficients for single-valve prototype operations were 0.82 for filling and 0.62 for emptying.

Table 3 shows the model-prototype comparison for lock coefficients. The lock coefficient from the model dual-valve filling tests, 0.58, was increased 21 percent to 0.70 to make design calculations for the prototype. The model lock coefficient dual-valve emptying value, 0.44, was increased 23 percent to 0.54. The measured prototype values for dual-valve operations concur with these design estimates.

The model lock coefficient value for single-valve filling, 0.63, was increased 16 percent to 0.73 and the single-valve emptying value, 0.45, increased 16 percent to 0.52. These estimated lock coefficients are less than the measured prototype valves, 0.82 and 0.62, respectively.

In future design studies, it is recommended that estimated prototype lock coefficients should be based on increasing model lock coefficients by about 22 percent for two-valve operations and 35 percent for single-valve operations.

Culvert Pressures and Cavitation

The pressures below the valves and in the crossover area were acceptable during normal filling and emptying operations.

During the September experiments the culvert pressures downstream of the tainter valve dropped below the culvert roof for single-valve filling (Experiment 2-13) and both dual (Experiment 2-4) and single-valve emptying (Experiment 2-17). However, calculation of the cavitation parameter indicated very little potential for significant cavitation at these pressures.

The pressures in the crossover area dropped 11.4 ft below the culvert roof and 8.3 ft below pressure cell FE-5 during a September experiment for single-valve filling (Experiment 2-13). Problems with low pressures that accompany high velocities in the single-valve operations can be minimized by using the stepped valve operation. However, this lowest measured pressure, -8.3 ft, is above the recommended minimum bend pressure valve from EM 1110-2-1602 (HQUSACE 1980).

Valve Operation Times

The lock was designed for ideal operation with a valve time of 1.0 minute (60 seconds). Deviations from this valve time would change the ideal submergence on various lock components. The lock was evaluated in March with nominal valve times of 1, 2, and 4 minutes. During the September experiments, it became obvious that the valve operation time was dependent on the total head across the tainter valve.

No changes were made in the valve machinery settings between the March and September experiments. Experiment 30 from the March series, a normal fill experiment with a 20.0-ft tailwater, had a valve time of 76 seconds. A normal fill experiment from the September series, Experiment 2-3 with a 9.0-ft tailwater, had a valve time of 100 seconds. Additionally in September the right fill valve was set to a no-load time of 45 seconds. Experiment 2-15, a normal fill test, had a valve time of 79.5 seconds. Experiment 2-13, a right-side single-valve fill test, had a valve time of 96.0 seconds. These differences can be attributed only to increased head during the longer filling time of the single-valve operation.

General Instrumentation Facilities

The instrumentation facilities at the New Bonneville Lock functioned as designed. All 34 proposed flush-mounted pressure transducers were installed prior to the lock being flooded. Only one of the transducers (FS-4) failed to function during the March series, but it was installed in an area of ongoing construction. The design of the flush-mounted transducer boxes and the 2-in.-diameter cable conduits

routed to the ladder wells allowed for the successful installation of all the instrumentation. The successful installation of all the pressure transducers enabled the lock to be fully evaluated for both normal operations and single-valve operations on either side of the lock.

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Table 1
Summary of Instrumentation

Instrument Number	Type	Range psia	Location			Measurement	Computed Quantity	Comment
			Lock Feature	Station	El			
LT-1	Pressure cell	100	Culvert, ceiling, fill	22+90.60	-16.50	Pressure	Piezometric head	
LT-8	Pressure cell	100	Culvert, ceiling, fill	22+90.60	-16.50	Pressure	Piezometric head	
LT-2	Pressure cell	100	Culvert, ceiling, fill	24+20.00	-16.50	Pressure	Piezometric head	
LT-7	Pressure cell	100	Culvert, ceiling, fill	24+20.00	-16.50	Pressure	Piezometric head	
LT-3	Pressure cell	100	Culvert, ceiling, fill	25+50.00	-16.50	Pressure	Piezometric head	
LT-6	Pressure cell	50	Culvert, ceiling, fill	25+50.00	-16.50	Pressure	Piezometric head	
LT-4	Pressure cell	50	Culvert, ceiling, empty	29+78.00	-20.00	Pressure	Piezometric head	
LT-5	Pressure cell	50	Culvert, ceiling, empty	29+78.00	-20.00	Pressure	Piezometric head	
FM-1	Pressure cell	50	Filling manifold, ceiling	23+50.20	-17.00	Pressure	Piezometric head	
FM-4	Pressure cell	50	Filling manifold, ceiling	23+50.20	-17.00	Pressure	Piezometric head	
FM-2	Pressure cell	50	Filling manifold, ceiling	25+10.20	-17.00	Pressure	Piezometric head	
FM-3	Pressure cell	50	Filling manifold, ceiling	25+10.20	-17.00	Pressure	Piezometric head	
FM-5	Pressure cell	50	Filling manifold, ceiling	27+08.0	-17.00	Pressure	Piezometric head	
FM-8	Pressure cell	50	Filling manifold, ceiling	27+08.10	-17.00	Pressure	Piezometric head	
FM-6	Pressure cell	50	Filling manifold, ceiling	28+68.10	-17.00	Pressure	Piezometric head	
FM-7	Pressure cell	50	Filling manifold, ceiling	28+68.10	-17.00	Pressure	Piezometric head	
FS-1	Pressure cell	100	Horizontal divider	26+09.17	-24.25	Pressure	Piezometric head	
FS-4	Pressure cell	100	Horizontal divider	26+09.17	-24.25	Pressure	Piezometric head	Bad gauge
FS-2	Pressure cell	100	Horizontal divider	26+09.17	-23.25	Pressure	Piezometric head	
FS-5	Pressure cell	100	Horizontal divider	26+09.17	-23.25	Pressure	Piezometric head	

(Sheet 1 of 3)

Table 1 (Continued)

Instrument Number	Type	Range psia	Location			Measurement	Computed Quantity	Comment
			Lock Feature	Station	El			
FS-3	Pressure cell	100	Horizontal Divider	26+09.17	-25.25	Pressure	Piezometric head	
FS-6	Pressure cell	100	Horizontal Divider	26+09.17	-25.25	Pressure	Piezometric head	
EM-1	Pressure cell	50	Emptying manifold, ceiling	30+23.92	-20.00	Pressure	Piezometric head	
EM-2	Pressure cell	50	Emptying manifold, ceiling	30+67.42	-20.00	Pressure	Piezometric head	
EM-3	Pressure cell	50	Emptying manifold, ceiling	30+67.42	-20.00	Pressure	Piezometric head	
EM-4	Pressure cell	50	Emptying manifold, ceiling	30+23.92	-20.00	Pressure	Piezometric head	
FE-1	Pressure cell	100	Tainter valve liner, ceiling	23+41.60	-17.00	Pressure	Piezometric head	Sept. testing
FE-4	Pressure cell	100	Tainter valve liner, ceiling	22+41.60	-17.00	Pressure	Piezometric head	Sept. testing
FE-2	Pressure cell	100	Tainter valve liner, ceiling	29+10.70	-18.00	Pressure	Piezometric head	Sept. testing
FE-3	Pressure cell	100	Tainter valve liner, ceiling	29+10.70	-18.00	Pressure	Piezometric head	
FE-5	Pressure cell	100	Crossover wall	25+96.00	-20.10	Pressure	Piezometric head	Sept. testing
FE-6	Pressure cell	100	Crossover wall	26+22.40	-28.40	Pressure	Piezometric head	Sept. testing
FE-7	Pressure cell	100	Crossover wall	26+22.40	-20.10	Pressure	Piezometric head	
FE-8	Pressure cell	100	Crossover wall	25+96.00	-28.40	Pressure	Piezometric head	
WSFR	Pressure cell	50	Valve well	22+18	-10.00	Pressure	Water level	
WSFL	Pressure cell	50	Valve well	22+18	-10.00	Pressure	Water level	
WSER	Pressure cell	50	Valve well	28+88	-10.00	Pressure	Water level	
WSEL	Pressure cell	50	Valve well	28+88	-10.00	Pressure	Water level	
LWR-1	Pressure cell	50	Lock water surface	22+90	16.5	Pressure	Water level	
LWR-3	Pressure cell	50	Lock water surface	26+55	16.5	Pressure	Water level	Sept. testing

(Sheet 2 of 3)

Table 1 (Concluded)

Instrument Number	Type	Range psia	Location			Measurement	Computed Quantity	Comment
			Lock Feature	Station	El			
LWR-4	Pressure cell	50	Lock water surface	28+50	16.5	Pressure	Water level	
LWL-3	Pressure cell	50	Lock water surface	26+55	16.5	Pressure	Water level	
WUS	Pressure cell	15	Upstream water el	21+86	71.5	Pressure	Water level	Sept. testing
WDS1	Pressure cell	15	Downstream water el	29+70	16.5	Pressure	Water level	Sept. testing
WDS2	Pressure cell	15	Downstream water el	30+97	16.5	Pressure	Water level	
USM	Micro switch	Open/close	Miter gate opens			Open/close	Time of opening	
DSM	Micro switch	Open/close	Miter gate opens			Open/close	Time of opening	
VFR	Potentiometer	15 ft	Tainter valve	23+35		Linear motion	Valve opening, ft	Sept. testing
VFL	Potentiometer	15 ft	Tainter valve	23+35		Linear motion	Valve opening, ft	Sept. testing
VER	Potentiometer	15 ft	Tainter valve	29+05		Linear motion	Valve opening, ft	Sept. testing
VEL	Potentiometer	15 ft	Tainter valve	29+05		Linear motion	Valve opening, ft	

(Sheet 3 of 3)

Table 2
Test Conditions

Experiment Number	Experiment Type	Water-Surface El		Tainter Valve Time, sec		Fill/Empty Time, sec	Overfill/ Underfill, ft	Miter Gate Opening Time sec	Comment
		Upstream Pool	Downstream Pool	Left	Right				
2	2VF	74.2	20.25	81	77.5	444.5	1.5	458	
4	2VE	74.1	20.8	69.5	72	554.5	-1.1	574	
6	SFR	74.75	20.75	-	81.5	777	0.8	806	
8	SER	74.35	21.35	-	74	1,016.5	-0.5	1054	
10	SFL	74.4	21.25	81.5	-	760	1	794	
11	SEL	74.3	21.3	69.5	-	1,048	-0.6	1,080.5	
12	2VF	74.3	25	72	72	428.5[1]	-1.4	495.5	
15	2VF	73.3	20.7	152	153	478	1.6	500	2-min valve time
16	2VE	73.5	20.45	149	143	581[1]	-	953	2-min valve time
18	2VF	73.7	20.6	311.5	324.5	579.5	1.4	593	4-min valve time
19	2VE	73.8	20.55	295	310	672[1]	1.3[1]	831	4-min valve time
21	SFR	74	24.9	-	76.5	NC	-		High chamber elevation
23	SFL	73.9	24.55	81	-	NC	-		
25	SFL	74	20.25	373.5	-	NC	-		294.5-sec step
27	SFL	73	19.5	389	-	981.5[1]	-		303.0-sec step
30	2VF	72.9	20	76	77	446	1.5[1]		
31	SFL	73.3	20.35	380.5	-	NC	NC		303.0-sec step
32	SFL	73.55	20.25	85	-	769.4	0.8	804	
33	2VE	73.7	20.1	75	73.5	NC	NC		

(Continued)

Note: 2VF = 2-valve fill; 2VE = 2-valve empty; SFR = Single fill right side; SFL = Single fill left side; SER = Single empty right side; SEL = Single empty left side; NC = Not completed.
[1] Estimate time or distance.

Table 2 (Concluded)

Experiment Number	Experiment Type	Water-Surface El		Tainter Valve Time, sec		Fill/Empty Time, sec	Overfill/ Underfill, ft	Miter Gate Opening Time sec	Comment
		Upstream Pool	Downstream Pool	Left	Right				
34	2VF	73.8	20.65	79	80	456.2	1.6		
2-3	2VF	74.3	9	99.5	100.5	509	1.4		
2-4	2VE	74.45	8.8	Unknown	128	NC	-		
2-5	SFR	74.45	8.55	-	397	1,135.5[1]	0.85[1]		294.5-sec step
2-7	SER	74.8	8.3	-	426	1,380	-0.8		294.5-sec step
2-9	2VF	74.4	10.65	220	213.5	580.5	1.25		3.5-min valve time
2-11	2VE	74.8	10.6	Unknown	217.5	695.5[1]	-0.8[1]		3.5-min valve time
2-12	2VF	74.7	10.6	84.5	80.5	502.5	1.15[1]		
2-13	SFR	74.8	10.45	-	96	864	0.8		
2-14	2VE	74.9	10.4	Unknown	105.5	627[1]	-1.5[1]		
2-15	2VF	74.7	10.55	88	79.5	497.0[1]	1.4[1]		511.5-sec fill time
2-16	SFR	74.8	10.4	-	385.5	1,093.5[1]	0.6[1]		305-sec step; 1,212.0 sec empty time
2-17	SER	74.9	10.4	-	134.5	1,138	-0.65		

Table 3
Culvert Coefficients and Lock Coefficients

Experiment Number	Experiment Type	Culvert Coefficient C	Lock Coefficient C_L
2	2-Valve Fill, March Tests	0.73	0.72
15		0.71	0.72
18		0.72	0.72
30		0.72	0.71
2-Valve Average, March Tests		0.72	0.72
2-3	2-Valve Fill, September Tests	0.72	0.71
2-9		0.72	0.70
2-12		0.72	0.71
2-15		0.72	0.72
2-Valve Average, September Tests		0.72	0.71
6	Single Fill, Right Side	0.82	0.82
2-13		0.83	0.82
10	Single Fill, Left Side	0.83	0.83
32		0.83	0.82
Single Fill, Average		0.83	0.82
4	2-Valve Empty, March Tests	0.56	0.57
16		0.57	0.57
19		0.58	0.56
2-Valve Empty, March Average		0.57	0.57
2-11	2-Valve Empty, September Tests	0.57	0.57
2-14		0.56	0.56
2-Valve Empty, September Average		0.56	0.56
8	Single Empty, Right Side	0.62	0.63
2-17		0.62	0.63
11	Single Empty, Left Side	0.60	0.60
Single Empty, Average		0.61	0.62

Table 4
Lock Loss Coefficients

Experiment Number	Experiment Type	V_c fps	$Z_u - z$, ft	Loss Coefficient, k_t
2	2-Valve Fill, March Tests	39.5	45.9	1.90
15		35.3	38.2	1.97
18		30.2	27.1	1.91
30		35.9	38.3	1.92
2-Valve Average, March Tests				1.92
2-3	2-Valve Fill, September Tests	42.7	1.94	1.94
2-9		37.8	42.8	1.92
2-12		42.7	55.2	1.95
2-15		42.8	55.3	1.94
2-Valve Average, September Tests				1.94
6	Single Fill, Right Side	46.3	49.5	1.49
2-13		50.6	58.3	1.46
10	Single Fill, Left Side	46.5	48.3	1.44
32		42.2	40.1	1.45
Single Fill, Average				1.46
4	2-Valve Empty, March Tests	31.2	47.7	3.14
16		29.1	40.9	3.12
19		25.7	30.7	3.00
2-Valve Empty, March Average				3.09
2-11	2-Valve Empty, September Tests	30.6	44.2	3.03
2-14		33.3	54.1	3.14
2-Valve Empty, September Average				3.08
8	Single Empty, Right Side	35.0	49.9	2.62
2-17		33.6	56.1	2.60
11	Single Empty, Left Side	34.1	50.2	2.77
Single Empty, Average				2.66

Table 5
Model-Prototype Comparison

Condition	Model (M) or Prototype (P)	C_L	k_t	Percent Change of Prototype Relative to Model for C_L
		Filling		
2 Valve	M	0.58	3.00	
	P[1]	0.70	2.05	21
	P	0.71	1.93	23
1 Valve	M	0.63	2.54	
	P[1]	0.73	1.90	16
	P	0.82	1.46	31
		Emptying		
2 Valve	M	0.44	5.24	
	P[1]	0.54	3.47	23
	P	0.57	3.09	30
1 Valve	M	0.45	4.96	
	P[1]	0.52	3.71	16
	P	0.62	2.66	38

[1] Estimated.

Table 6
Minimum Piezometric Pressures in the Filling and Emptying System, March Series, ft NGVD

Experiment Number	Channel Number	Start Time	Mean Value	Minimum Value	Maximum Value	Peak-to-Peak Value	Standard Deviation
2-Valve Fill							
2	WSFL	86.8	46	45.5	46.4	0.9	0.17
2	FE-4	42.9	11.4	9.6	13.5	3.9	0.73
2	LT-8	31.2	19.9	13.2	23.9	10.7	1.87
2	FE-7	81.4	12.4	9	16.8	7.7	1.19
2	FE-8	82.9	17.1	14.4	19.3	4.9	0.84
2	WSFR	82.9	46.7	46.3	47.3	1	0.19
2	FE-1	42.1	11.7	8.7	14.4	5.7	0.77
2	LT-1	35.1	22.3	9.6	34.8	25.2	2.95
2	FE-5	79.8	15.3	12.7	17.7	5	0.84
2	FE-6	80.6	16.6	13.4	19.5	6.1	1.12
15	WSFL	151.2	49	48.7	49.4	0.8	0.13
15	FE-4	82.6	8.5	6.1	10	3.9	0.74
15	LT-8	57.1	16.7	10.3	21	10.7	2.27
15	FE-7	146.3	20.4	17.6	23.5	5.8	0.91
15	FE-8	80.6	22.8	20.6	24.8	4.2	0.49
15	WSFR	145.3	49.8	49.3	50.6	1.3	0.23
15	FE-1	78.6	8.7	4.4	15.9	11.5	0.79
15	LT-1	42.4	17.7	13.4	21.4	8	1.47
15	FE-5	132.6	22.4	20.4	24.2	3.8	0.64
15	FE-6	128.6	23.4	21.2	25.4	4.2	0.74
18	WSFL	289.9	55.8	55.4	56.2	0.8	0.13
18	FE-4	152.6	9.9	8	12.8	4.7	0.43
18	LT-8	109.5	14.3	9.6	18.4	8.7	1.7
18	FE-7	33	21	20.7	21.2	0.6	0.1
18	FE-8	31.1	21	20.7	21.4	0.7	0.12
18	WSFR	303.6	57.4	57.2	57.7	0.6	0.1
18	FE-1	144.8	10.8	8.9	11.4	2.5	0.4
18	LT-1	133	18.3	9.5	23.4	13.9	2.28
18	FE-5	35	21	20.7	21.3	0.7	0.12

(Continued)

Table 6 (Concluded)							
Experiment Number	Channel Number	Start Time	Mean Value	Minimum Value	Maximum Value	Peak-to-Peak Value	Standard Deviation
2-Valve Fill (Continued)							
18	FE-6	31.1	21	20.7	21.3	0.6	0.12
Single-Valve Fill							
6	WSFR	105.6	37	36. 3	37.6	1.3	0.23
6	FE-1	46.3	6.2	4.3	8.6	4.2	0.66
6	LT-1	36.1	19.7	6.2	28.3	22.1	3.05
6	FE-5	94.2	-11	-14.7	-4.6	10.1	1.36
6	FE-6	96.5	-4.7	-8.7	0.1	8.8	1.6
10	WSFL	107	35.9	35.4	36.4	0.9	0.16
10	FE-4	50.5	6.2	3.4	8.9	5.5	0.94
10	LT-8	30.9	19.5	14.4	25.5	11.1	2.08
10	FE-7	99.1	-9.9	-14.2	-5.8	8.4	1.48
10	FE-8	92.8	-7.7	-11.1	-3.8	7.2	1.29
2-Valve Empty							
4	FE-3	37.3	5.9	3.9	7.3	3.4	0.57
4	LT-5	22.4	20.3	17.4	23.2	5.7	1.27
4	FE-2	42.8	5.2	2	7.7	5.7	0.9
4	LT-4	24.8	19.6	12.7	24.2	11.6	2.33
Single-Valve Empty							
8	FE-2	45.5	4.8	2	7.1	5.1	0.91
8	LT-4	25.7	20.2	15	24.5	9.4	2
11	FE-3	35.9	5	2.3	6.7	4.4	0.64
11	LT-5	19.4	20.6	17.2	26.9	9.7	1.85

Table 7
Minimum Piezometric Pressures in the Filling and Emptying System, September Series, ft NGVD

Experiment Number	Channel Number	Start Time	Mean Value	Minimum Value	Maximum Value	Peak-to-Peak Value	Standard Deviation
2-Valve Fill							
2-3	FE-1	49.4	-5.3	-10	-0.7	9.3	1.48
2-3	FE-4	50.8	-6.2	-10.8	-0.8	10	1.57
2-3	FE-5	65.8	9	0.2	18	17.8	1.87
2-3	FE-6	95.2	8	4.6	11.6	7	1.29
2-9	FE-1	108.7	-3.8	-11.4	-0.2	11.2	1.27
2-9	FE-4	112.6	-5.4	-9.1	2.6	11.6	1.43
2-9	FE-5	150.9	15.9	2.9	38.7	35.9	3.07
2-9	FE-6	150.9	16.5	5	37.6	32.5	3.03
2-12	FE-1	42.9	-1.8	-7.1	3.5	10.6	1.43
2-12	FE-4	47.5	-3.7	-7.8	0.5	8.4	1.39
2-12	FE-5	83.7	5.8	1.6	10	8.4	1.17
2-12	FE-6	81.2	7.7	4.1	13.1	9	1.45
2-15	FE-1	39.7	-2.1	-4.9	3	7.8	1
2-15	FE-4	45.9	-2.8	-9.3	3.1	12.4	1.58
2-15	FE-5	85.8	5.9	2.8	9.5	6.7	1.15
2-15	FE-6	78.8	7.7	4	11.6	7.7	1.23
Single-Valve Fill							
2-5	FE-1	31.4	-8.7	-13.4	-4.3	9	1.53
2-5	FE-5	422.3	-14.7	-18.9	-9.6	9.3	1.97
2-5	FE-6	410.6	-9.6	-15.4	-4.4	11	1.7
2-13	FE-1	64.6	-11	-20.9	21	41.9	4.08
2-13	FE-5	106.5	-23.4	-28.4	-16.5	11.9	1.88
2-13	FE-6	111.5	-18.2	-23.9	-11.1	12.8	2.06
2-16	FE-1	49.5	-10.2	-15.3	-6.7	8.7	1.24
2-16	FE-5	398.9	-8.5	-12.6	-3.7	8.9	1.45
2-16	FE-6	389.8	-4.6	-8.2	0.6	8.9	1.6

(Continued)

Table 7 (Concluded)							
Experiment Number	**Channel Number**	**Start Time**	**Mean Value**	**Minimum Value**	**Maximum Value**	**Peak-to-Peak Value**	**Standard Deviation**
2-Valve Empty							
2-4	FE-2	66.5	-15	-21	-5.6	15.4	1.7
2-11	FE-2	132.6	-12.7	-20.1	-7.2	12.9	1.57
2-14	FE-2	53.3	-11.3	-17	0.9	17.9	1.68
1-Valve Empty							
2-7	FE-2	362.4	-16.3	-20.2	-4.9	15.4	1.65
2-17	FE-2	69.7	-16.5	-22.2	-2.9	19.4	2.26

Table 8
Cavitation Parameter Calculations

Experiment Number	Time after Start, sec	b/B	H, ft	V_c, fps	C_c	$P/\gamma + Z_r$	σ
2	47	0.52	74.2	20.7	0.64	11.5	1.16
6	54	0.59	74.7	26.9	0.69	6.5	0.96
25	Valve Closing	0.51	74.0	36.5	0.93	-15.5[1]	0.47
2-12	46.5	0.48	72.6	23.2	0.69	-2.8	0.75
	53.5	0.52	72.6	23.2	0.63	-4.4	0.71
2-13	39.5	0.40	74.2	19.1	0.66	-7.8	0.64
	53.0	0.51	73.8	26.1	0.68	-13.3	0.53
	63.5	0.60	73.5	31.8	0.71	-13.3	0.52
2-13	62.4	0.59	73.5	31.8	0.69	-20.7[1]	0.40
2-14	62	0.50	57.2	23.5	0.70	-12.3	0.69
2-17	80	0.53	62.4	24.2	0.64	-17.9	0.53
2-17	80	0.53	62.4	24.2	0.63	-20.8[1]	0.48

[1] Nondecimated Data Minimum.

Table 9
Fill Test Piezometric Pressures in Filling Culverts after Tainter Valve Opens, ft NGVD

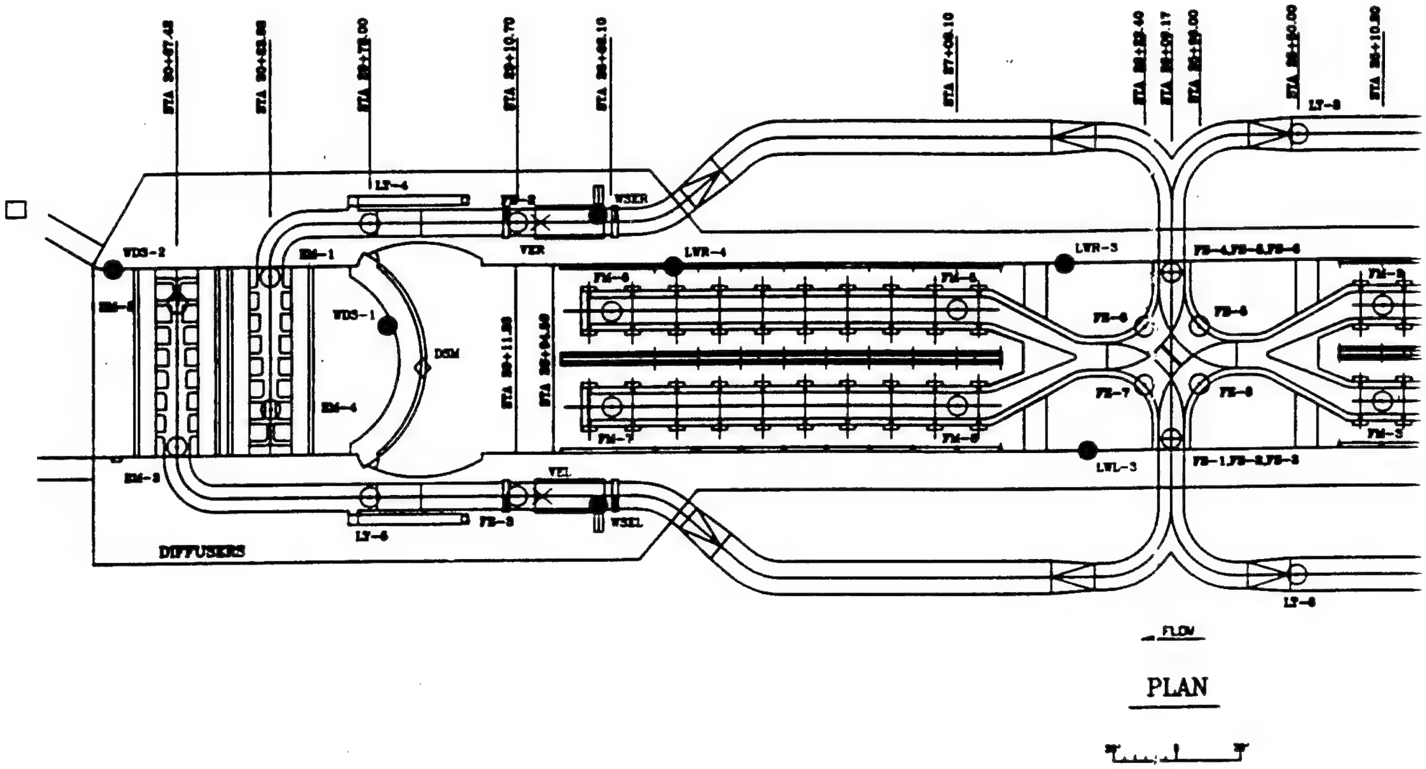
Experiment Number	Channel Number	Mean Value	Minimum Value	Maximum Value	Peak-to-Peak Value	Standard Deviation
2	FE-1	45.4	43.5	47.3	3.8	1.02
2	FE-4	44.7	43.3	46.2	2.9	0.95
2	LT-1	47.3	45.5	48.8	3.3	0.98
2	LT-8	46.8	45.3	48.5	3.2	0.96
2	LT-2	46.1	44.2	47.8	3.6	1.01
2	LT-7	45.9	44	47.7	3.7	1.1
2	LT-3	44.5	42.2	46.4	4.2	1.14
2	LT-6	44.4	41.8	46.2	4.4	1.28
15	FE-1	48.9	47.5	50.7	3.2	0.95
15	FE-4	48.3	46.8	50.2	3.4	0.97
15	LT-1	50.4	48.9	52	3.1	0.9
15	LT-8	50	48.5	51.5	3.1	0.94
15	LT-2	49.6	47.9	51.3	3.4	1.05
15	LT-7	49.4	47.8	51.2	3.4	1.05
15	LT-3	48.1	46.1	50.1	4	1.19
15	LT-6	48.1	46	50	3.9	1.17

Table 10
Fill Test Piezometric Pressures in Floor Manifold after Tainter Valve Opens, ft NGVD

Experiment Number	Channel Number	Mean Value	Minimum Value	Maximum Value	Peak-to-Peak Value	Standard Deviation
2	FM-1	53.5	50.1	55.5	5.3	1.55
2	FM-4	52.9	48.9	55.5	6.6	1.95
2	FM-6	51.7	47.7	54.3	6.6	1.94
2	FM-7	53.3	51	54.9	4	1
2	FM-2	35.4	32.6	38.2	5.6	1.69
2	FM-3	35.7	32.7	38.9	6.2	1.7
2	FM-5	35.5	32.6	38.5	5.9	1.69
2	FM-8	36.7	34.2	39.4	5.2	1.69
15	FM-1	56.1	53	57.8	4.9	1.31
15	FM-4	55.5	52.7	57.6	4.9	1.57
15	FM-6	54.4	51.1	56.8	5.7	1.67
15	FM-7	56.1	53.5	57.7	4.2	0.95
15	FM-2	40.8	38.4	43.3	4.9	1.47
15	FM-3	41	38.2	43.4	5.2	1.5
15	FM-5	40.7	37.7	43.4	5.7	1.51
15	FM-8	41.9	39.3	44.4	5.1	1.44
6	FM-1	29.3	27.2	31.4	4.2	1.23
6	FM-4	43.3	40.1	45.3	5.2	1.48
6	FM-6	30.3	28.5	31.9	3.4	0.99
6	FM-7	40.1	36.9	42	5.1	1.28
6	FM-2	27.2	25	29.4	4.4	1.15
6	FM-3	29.2	26.9	31.6	4.7	1.23
6	FM-5	27.1	25.1	29.3	4.2	1.07
6	FM-8	29.9	28.1	31.9	3.8	0.99
10	FM-1	40.8	38.4	42.5	4.1	1.11
10	FM-4	30.8	28.6	32.6	4.1	1.25
10	FM-6	41.2	37.5	43.5	6	1.84
10	FM-7	30.7	28.9	32.2	3.3	0.92
10	FM-2	29	27.1	31	3.9	1.07
10	FM-3	27.9	25.2	30.3	5.1	1.24
10	FM-5	29.7	27.1	31.9	4.8	1.24
10	FM-8	28.1	26	30.3	4.3	1.07

Table 11
Balance of Flow in Emptying System, Maximum Piezometric Pressures During Emptying Experiments, Two-Valve Emptying Experiments, ft NGVD

Experiment Number	Channel Number	Start Time	Mean Value	Minimum Value	Maximum Value	Peak to Peak Value	Standard Deviation
4	LT-4	55.9	26.1	23	29.3	6.4	1.01
4	LT-5	51.4	26	23.1	31.1	7.9	1.15
4	EM-1	62.2	26.3	22.7	28.7	5.9	0.94
4	EM-3	68.5	26.5	23.1	28.1	5	0.63
4	EM-2	65.3	34.5	32.7	35.9	3.2	0.73
4	EM-4	67.1	34.7	32.6	37.2	4.6	0.89
16	LT-4	124	24.9	20.7	27.2	6.5	1.01
16	LT-5	104.8	25.3	20.4	28.6	8.3	1.43
16	EM-1	140.8	25.7	24.2	26.8	2.7	0.44
16	EM-3	128.8	26.1	24.8	28.1	3.3	0.47
16	EM-2	139.2	33.6	32.7	35.3	2.6	0.48
16	EM-4	137.6	33.4	31.6	34.7	3.1	0.64
19	LT-4	255.9	23.7	20.7	26.5	5.7	1.07
19	LT-5	259.1	24.4	22.7	26	3.3	0.57
19	EM-1	268.7	24.2	22.9	25.4	2.5	0.5
19	EM-3	260.7	24.5	23.4	25.5	2.1	0.38
19	EM-4	273.6	30.3	28.9	31.3	2.4	0.5
19	EM-2	268.7	30	28.6	31.1	2.5	0.3

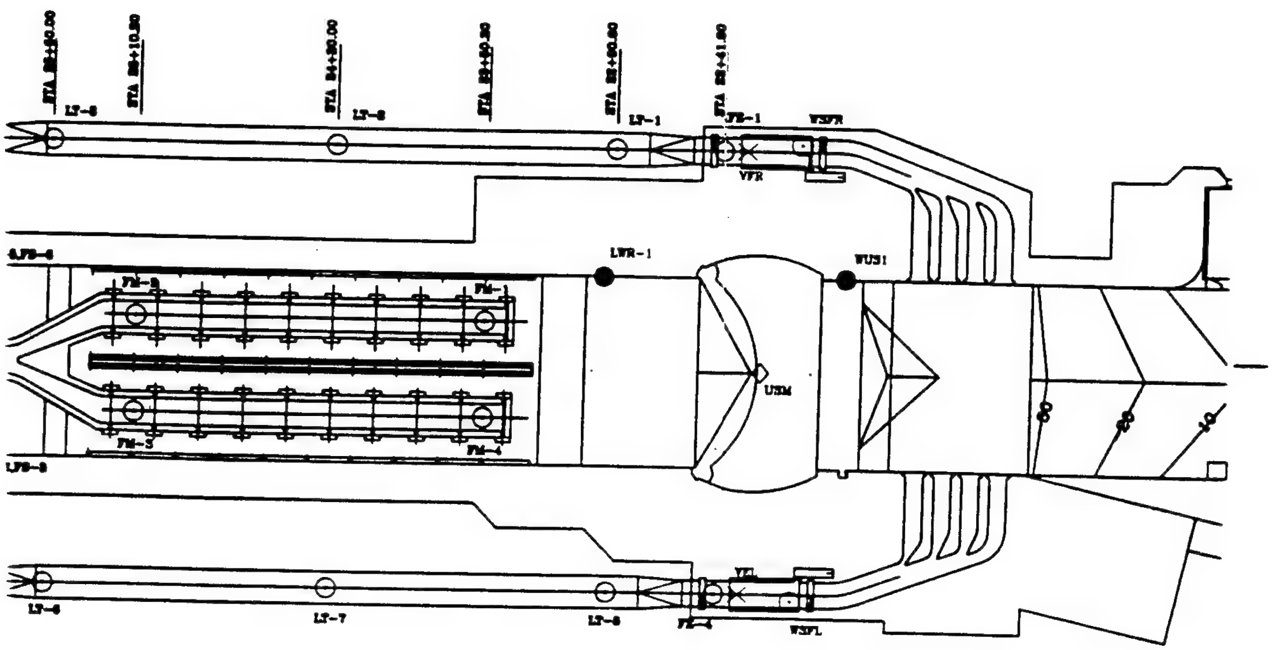


PLAN

LEGEND

- ● WATER SURFACE PRESSURE TRANSDUCER
- ⊙ EMBEDDED PRESSURE TRANSDUCER
- □ STAGE RECORDER
- × VALVE MOVEMENT POTENTIOMETER
- ◇ MITER GATE MICROSWITCH

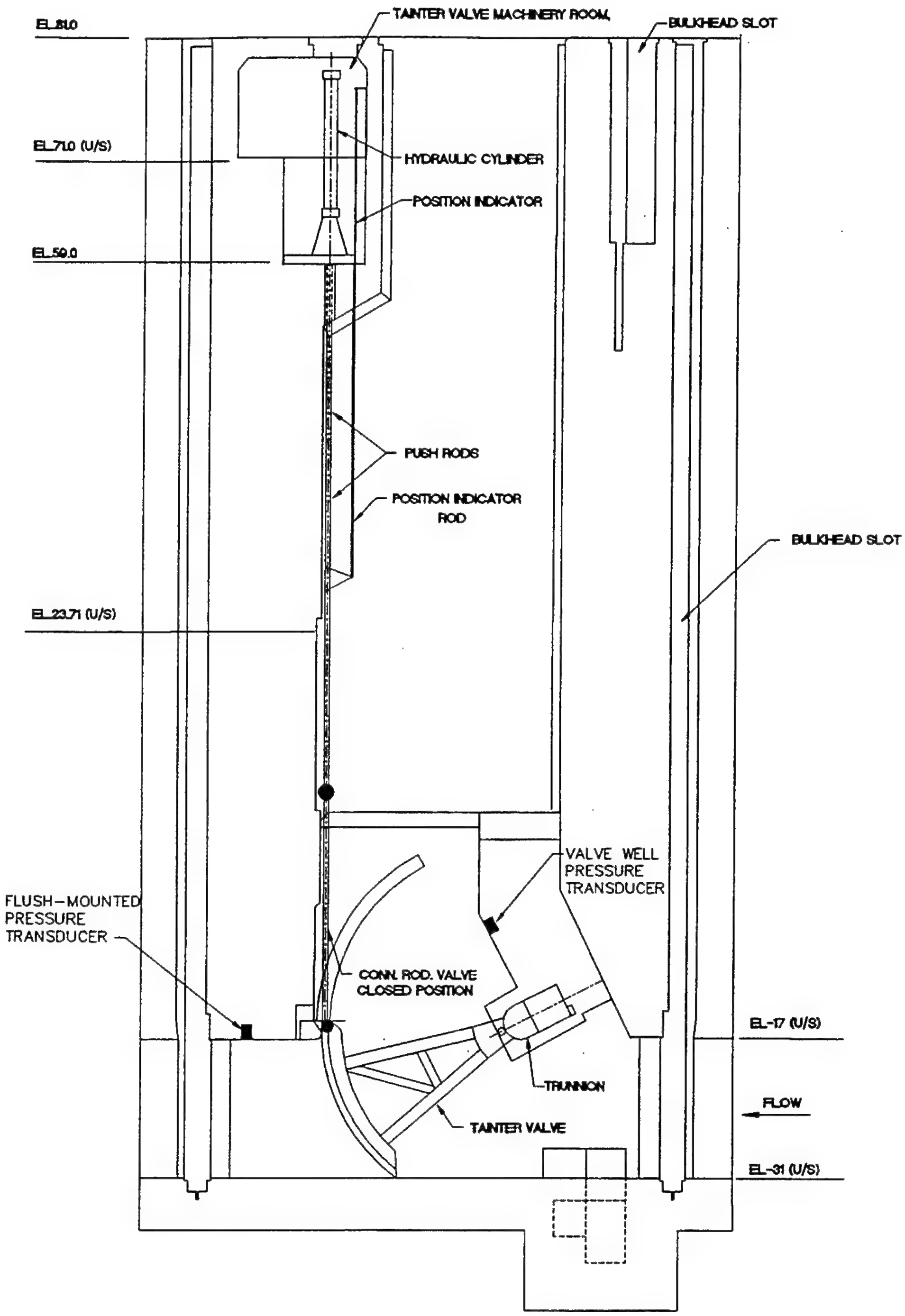
1



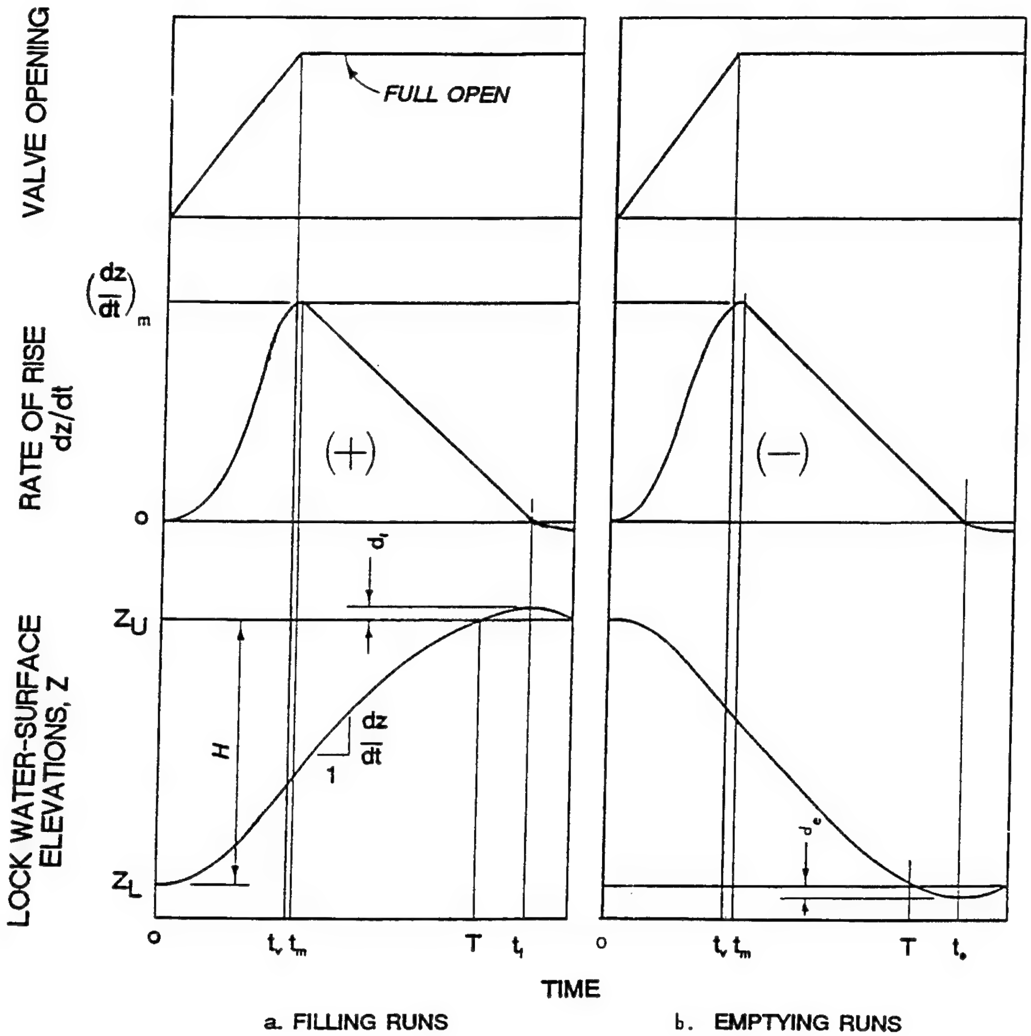
INSTRUMENTATION LOCATIONS

Plate 1

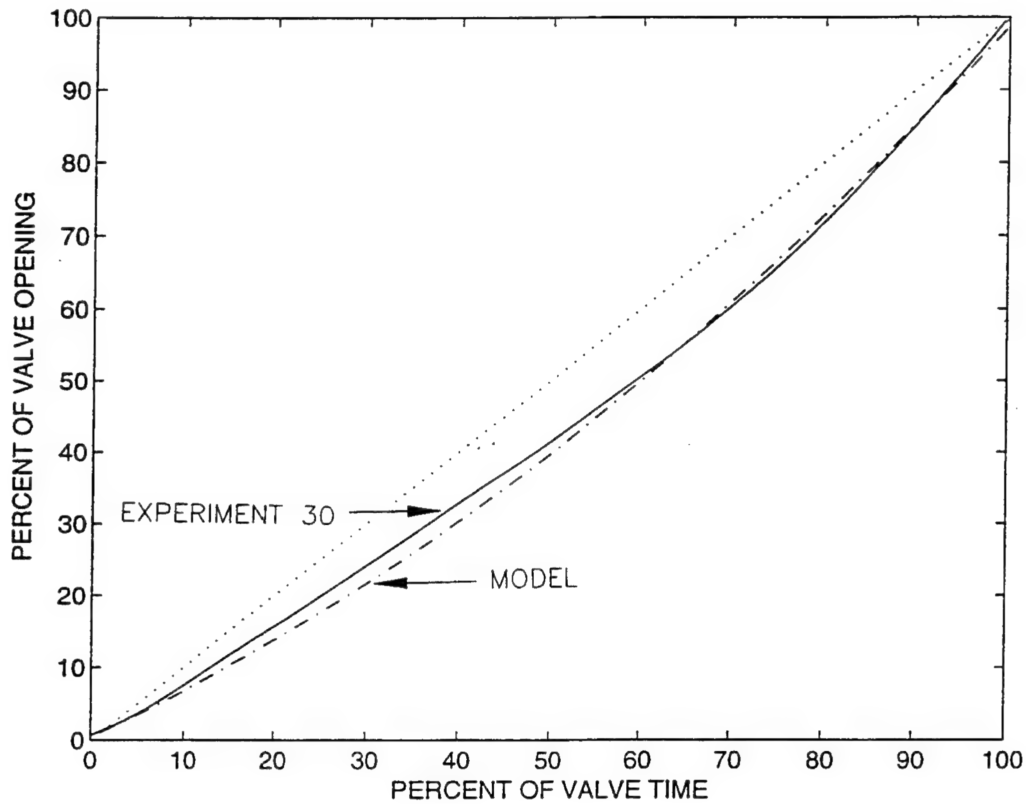
2



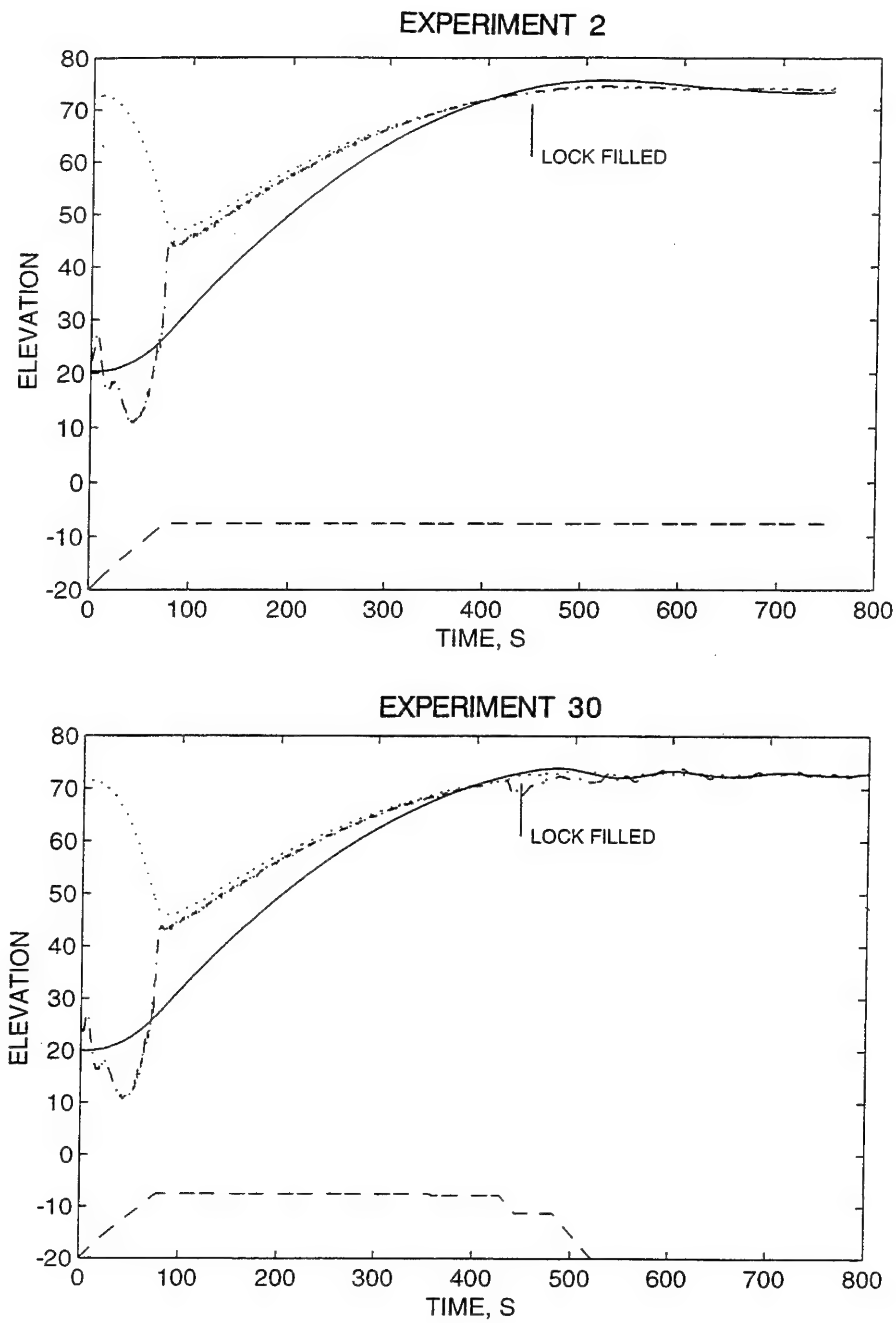
TAINTER VALVE MACHINERY AND PRESSURE TRANSDUCER LOCATIONS



DEFINITION SKETCH OF LOCK
PERFORMANCE PARAMETERS
FILLING AND EMPTYING



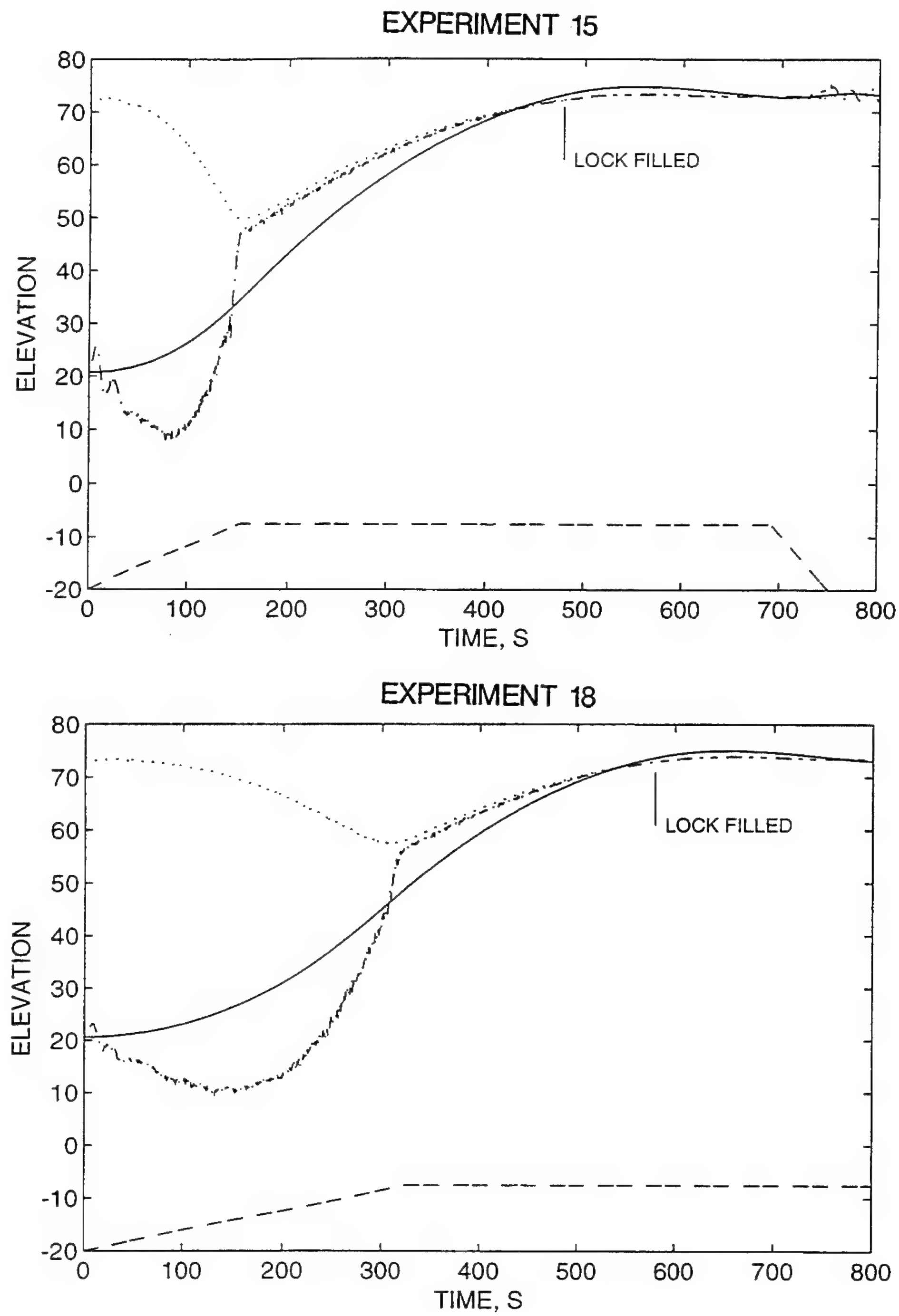
VALVE OPENING CALIBRATION
EXPERIMENT 30 AND PHYSICAL MODEL



LEGEND

—— LOCK WATER SURFACE
· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
· · · · VALVE WELL WATER SURFACE
— — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES
TWO-VALVE FILLING OPERATION
MARCH 1993
EXPERIMENTS 2 AND 30



LEGEND

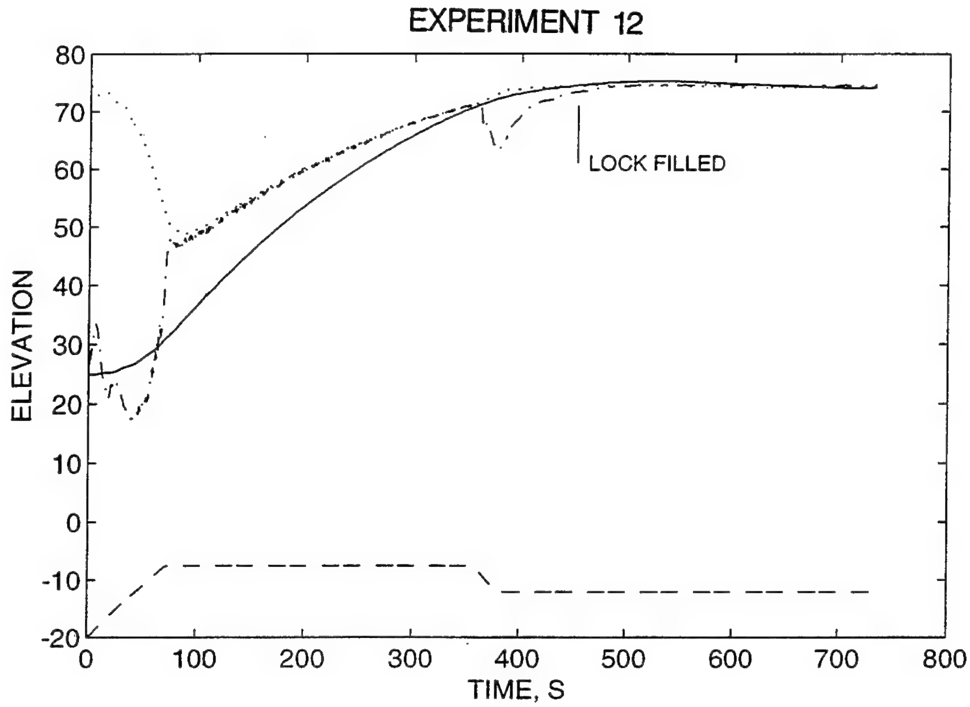
- LOCK WATER SURFACE
- PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- VALVE WELL WATER SURFACE
- VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

TWO-VALVE FILLING OPERATION

MARCH 1993

EXPERIMENTS 15 AND 18



LEGEND

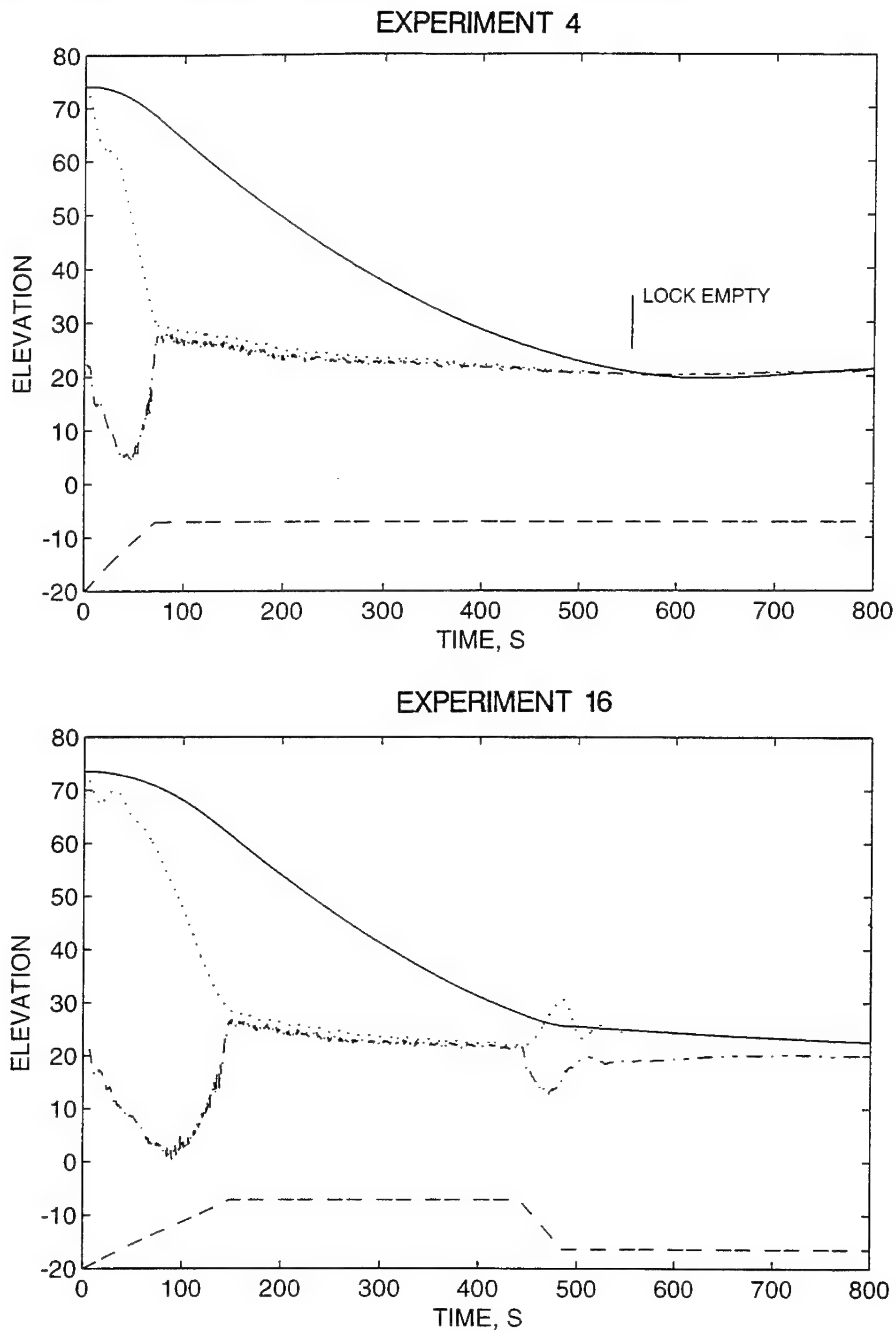
—— LOCK WATER SURFACE
· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
· · · · VALVE WELL WATER SURFACE
— — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

TWO-VALVE FILLING OPERATION

MARCH 1993

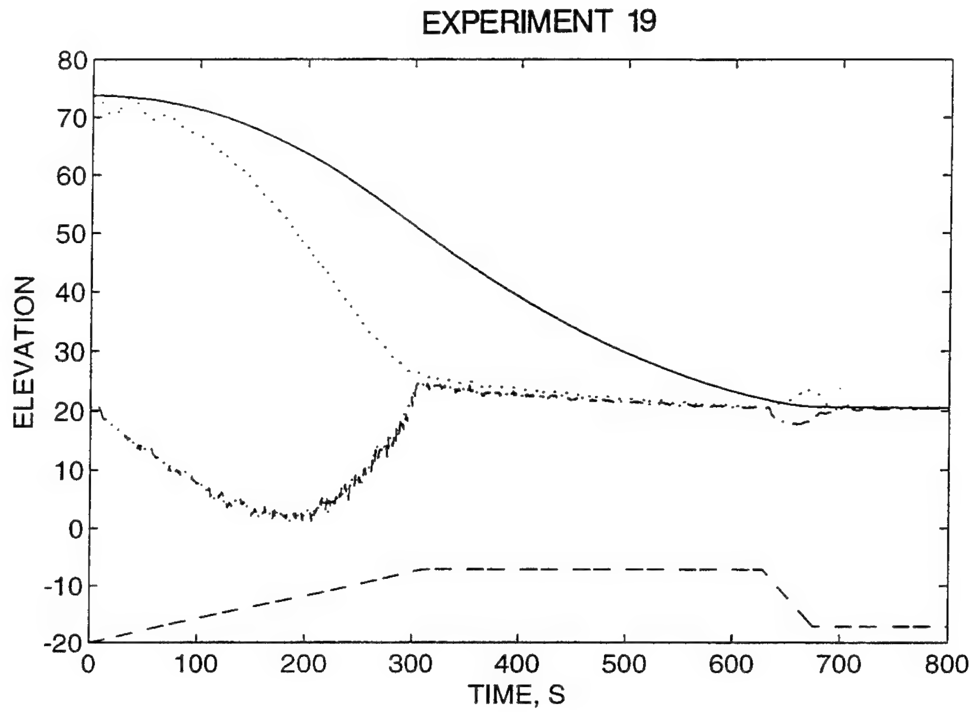
EXPERIMENT 12



LEGEND

—— LOCK WATER SURFACE
·—· PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
···· VALVE WELL WATER SURFACE
— — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES
TWO-VALVE EMPTYING OPERATION
MARCH 1993
EXPERIMENTS 4 AND 16



LEGEND

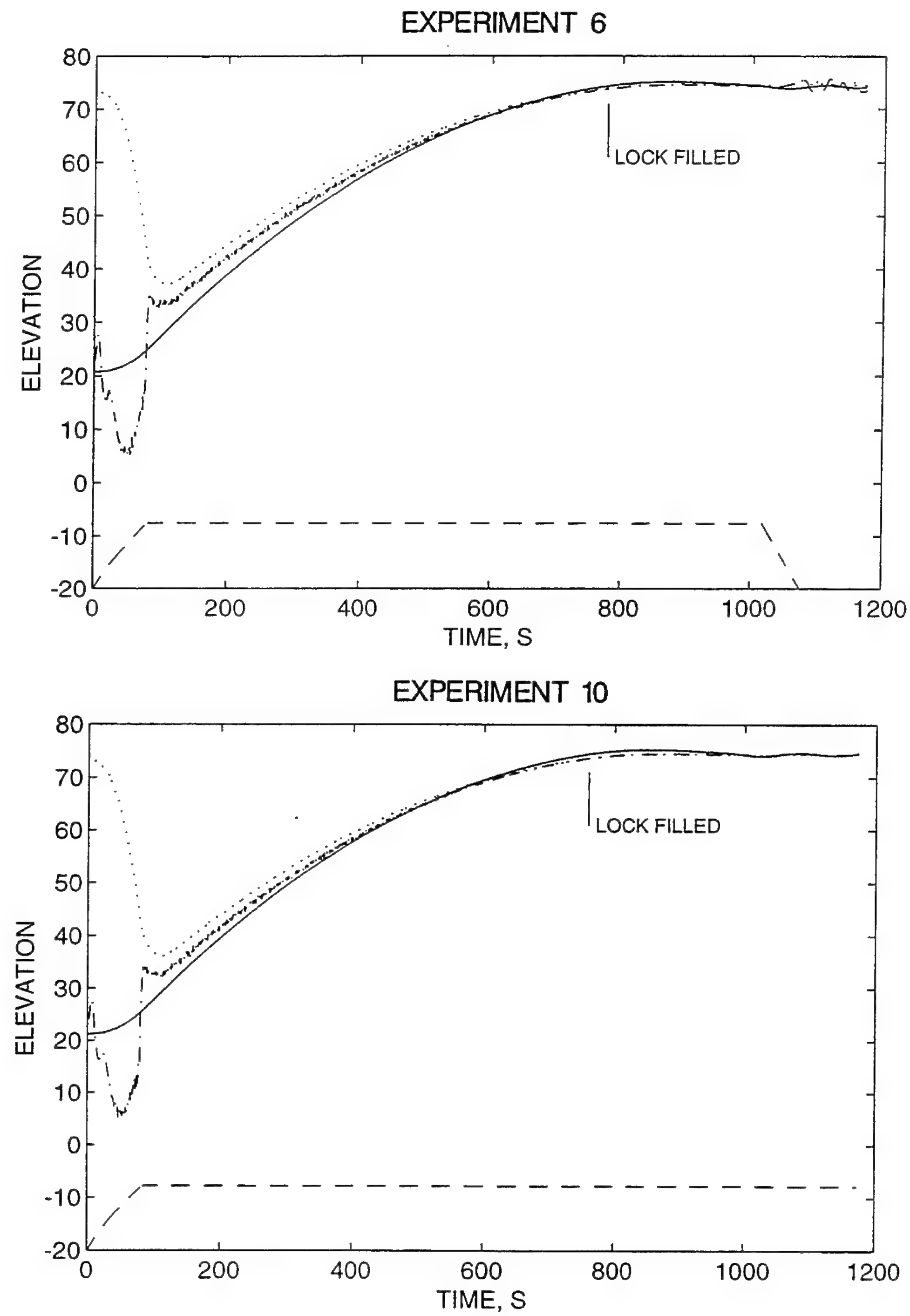
—— LOCK WATER SURFACE

· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE

· · · · VALVE WELL WATER SURFACE

— — VALVE OPENING

WATER-SURFACE ELEVATIONS
AND CULVERT PRESSURES
TWO-VALVE EMPTYING OPERATION
MARCH 1993
EXPERIMENT 19



LEGEND

—— LOCK WATER SURFACE

-·-· PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE

···· VALVE WELL WATER SURFACE

— — VALVE OPENING

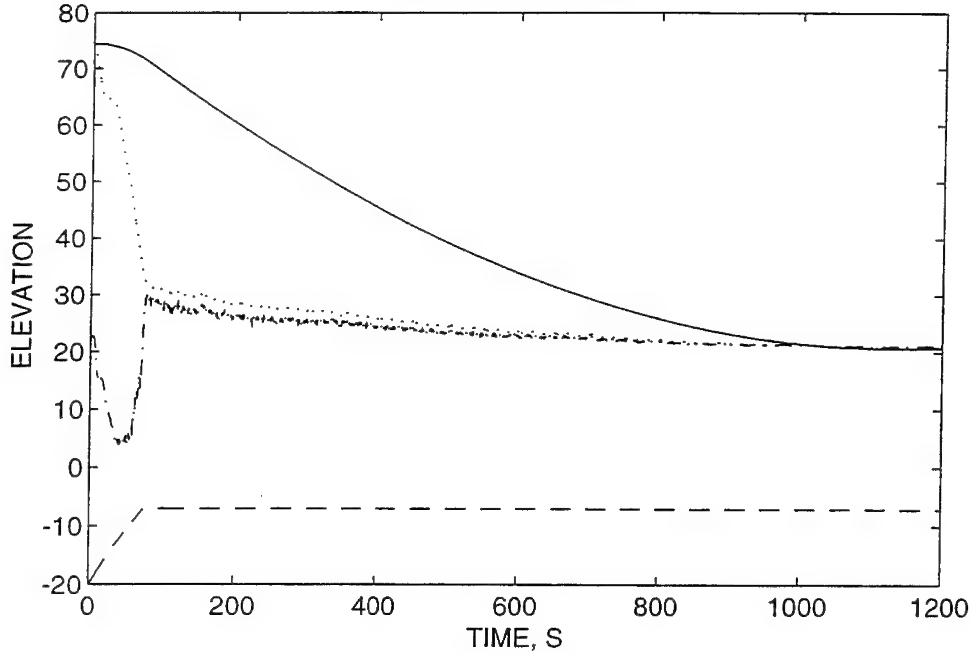
WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

ONE-VALVE FILLING OPERATION

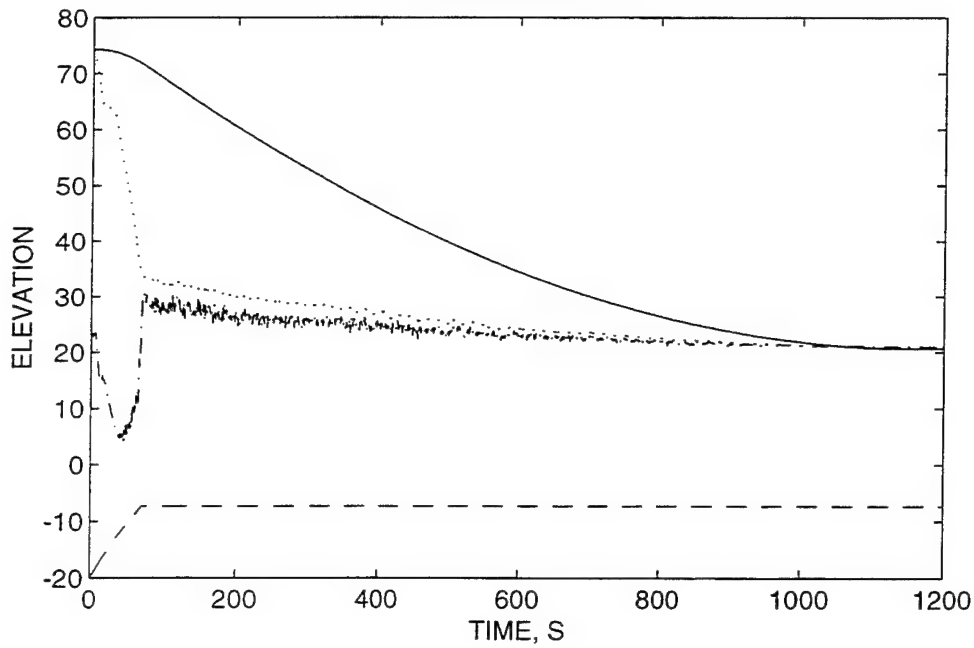
MARCH 1993

EXPERIMENTS 6 AND 10

EXPERIMENT 8



EXPERIMENT 11



LEGEND

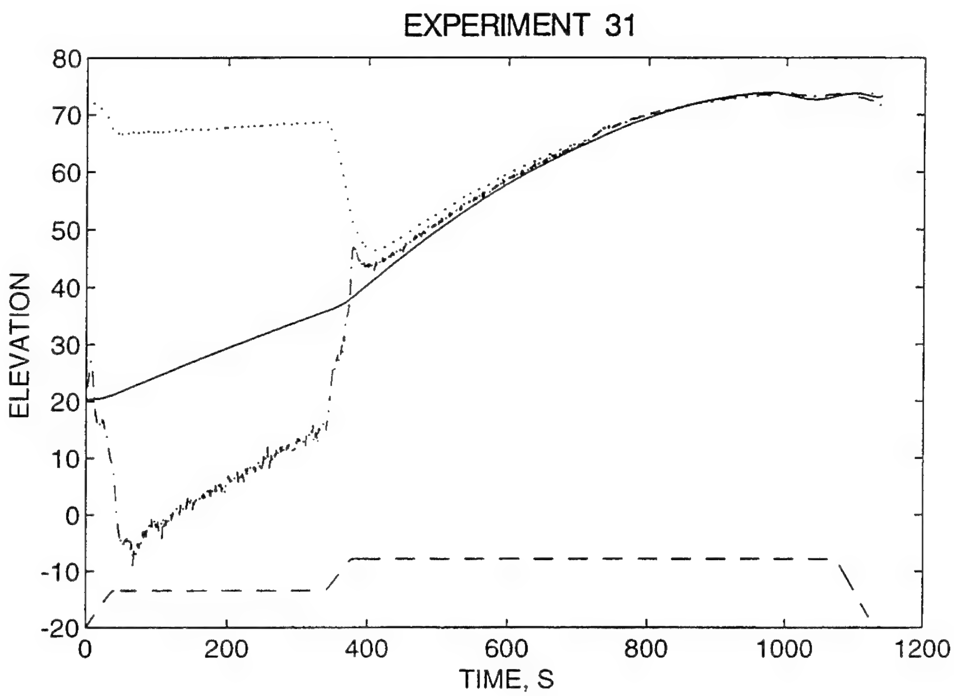
- ——— LOCK WATER SURFACE
- · — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- · · · · VALVE WELL WATER SURFACE
- — — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

ONE-VALVE EMPTYING OPERATION

MARCH 1993

EXPERIMENTS 8 AND 11



LEGEND

—— LOCK WATER SURFACE

· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE

· · · · VALVE WELL WATER SURFACE

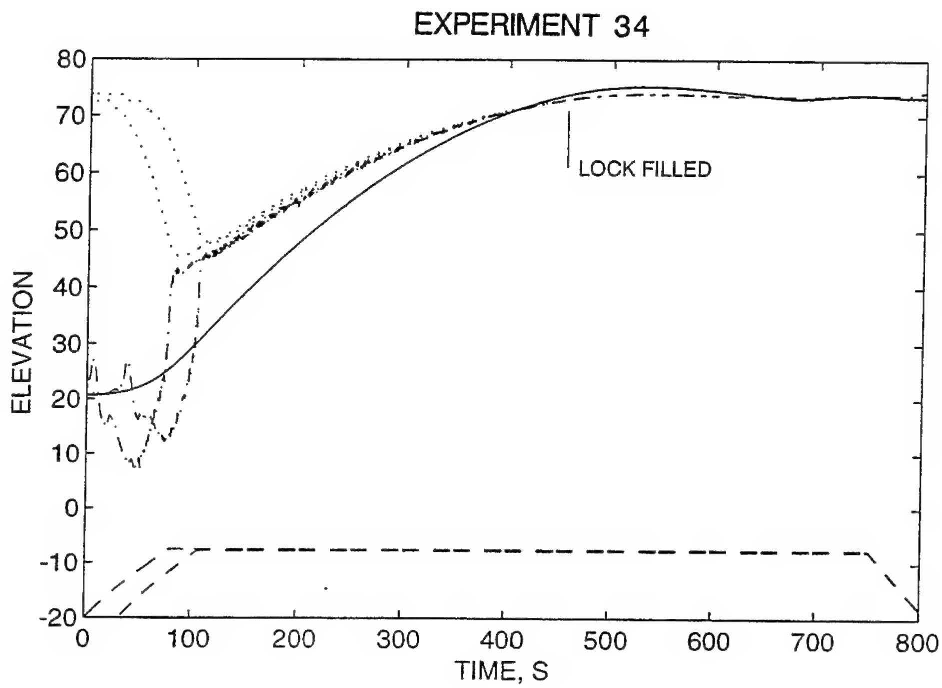
— — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

ONE-VALVE (STEPPED) FILLING OPERATION

MARCH 1993

EXPERIMENT 31



LEGEND

—— LOCK WATER SURFACE

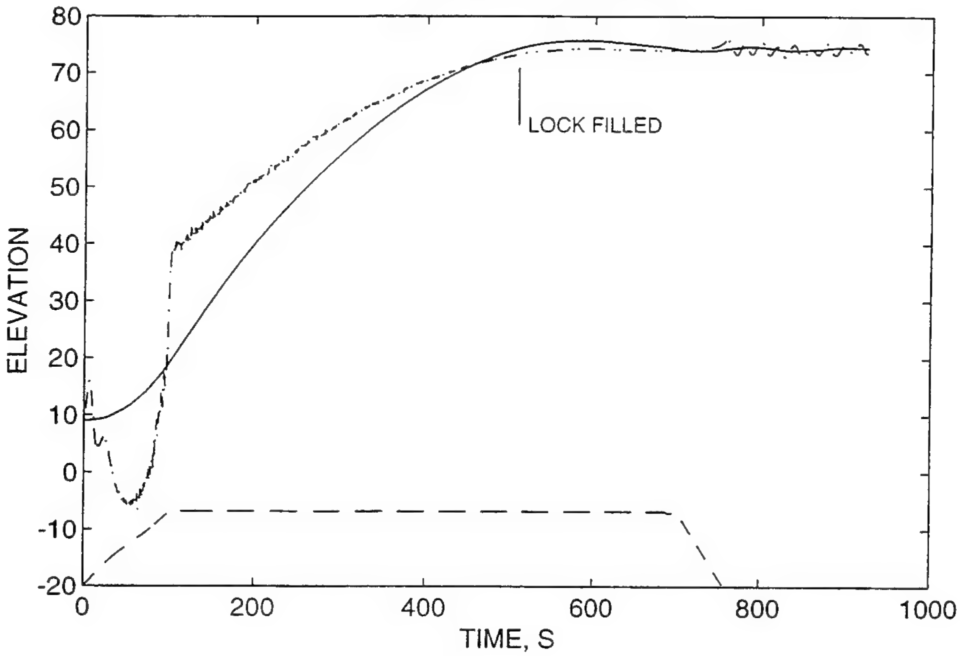
· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE

· · · · VALVE WELL WATER SURFACE

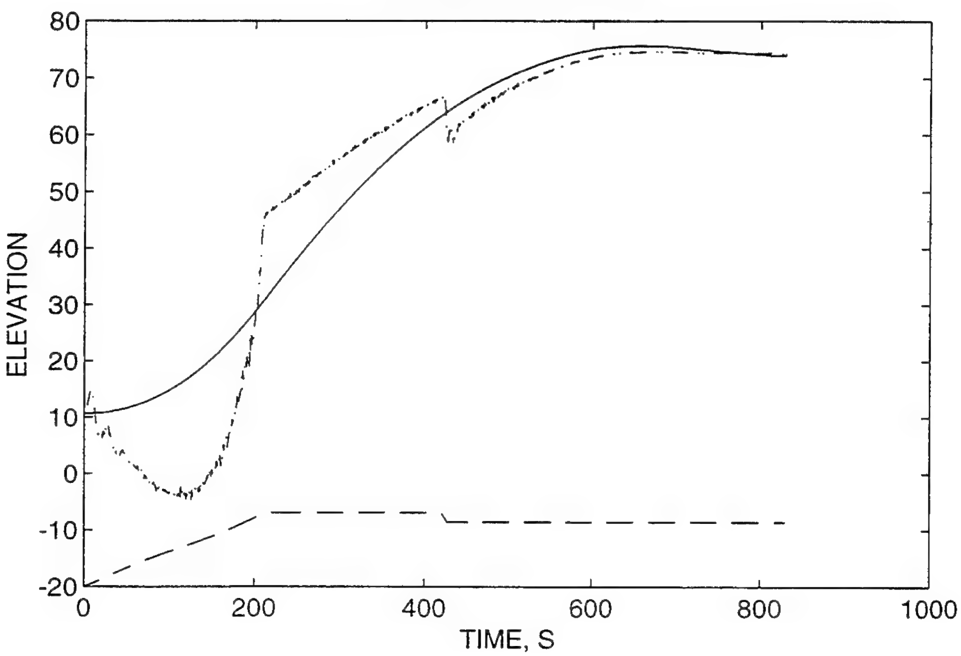
— — VALVE OPENING

WATER-SURFACE ELEVATIONS
AND CULVERT PRESSURES
TWO-VALVE (STAGGERED) FILLING OPERATION
MARCH 1993
EXPERIMENT 34

EXPERIMENT 2-3



EXPERIMENT 2-9



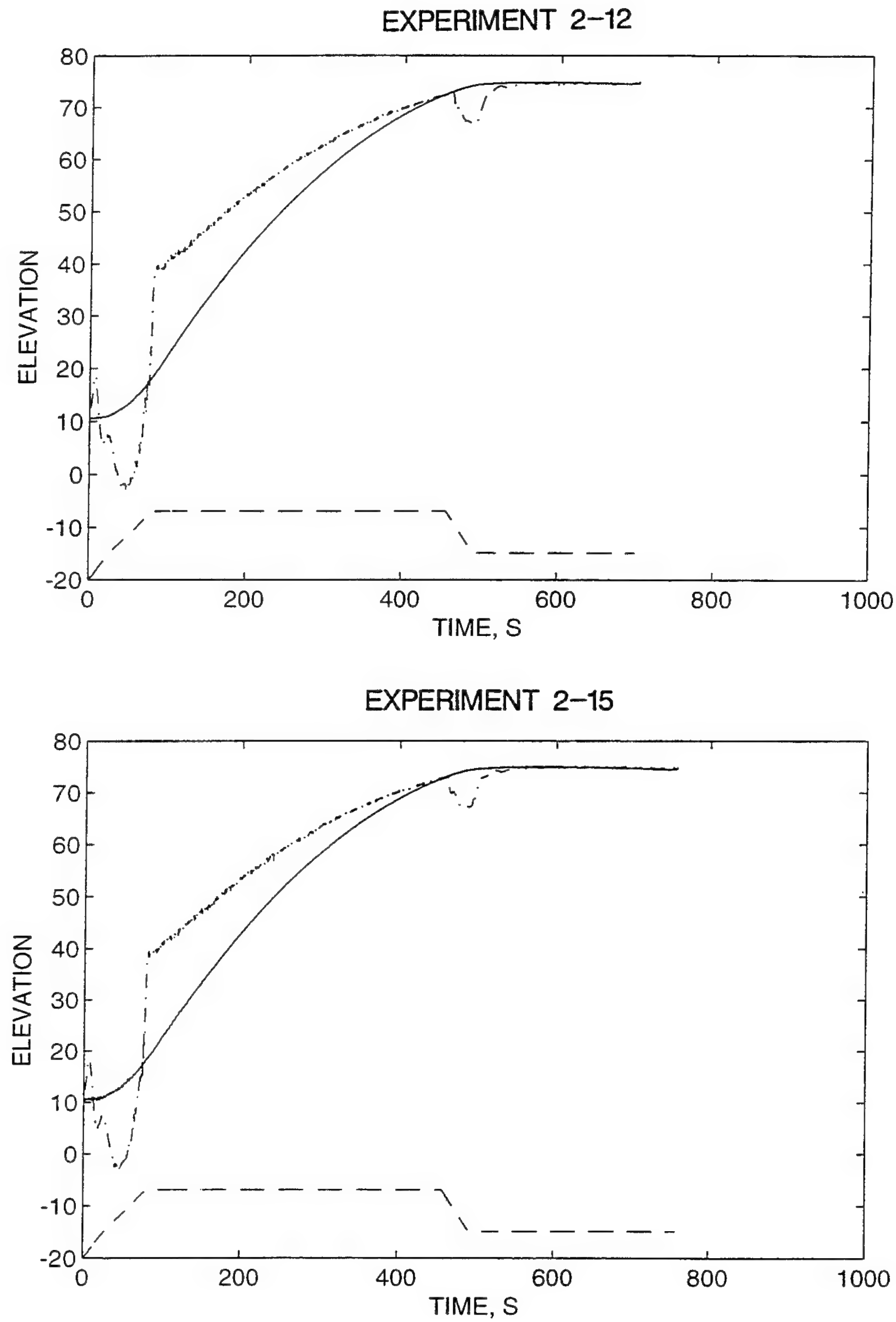
LEGEND

- —— LOCK WATER SURFACE
- · — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- · · · · VALVE WELL WATER SURFACE
- — — VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

TWO-VALVE FILLING OPERATION

SEPTEMBER 1993
EXPERIMENTS 2-3 AND 2-9



LEGEND

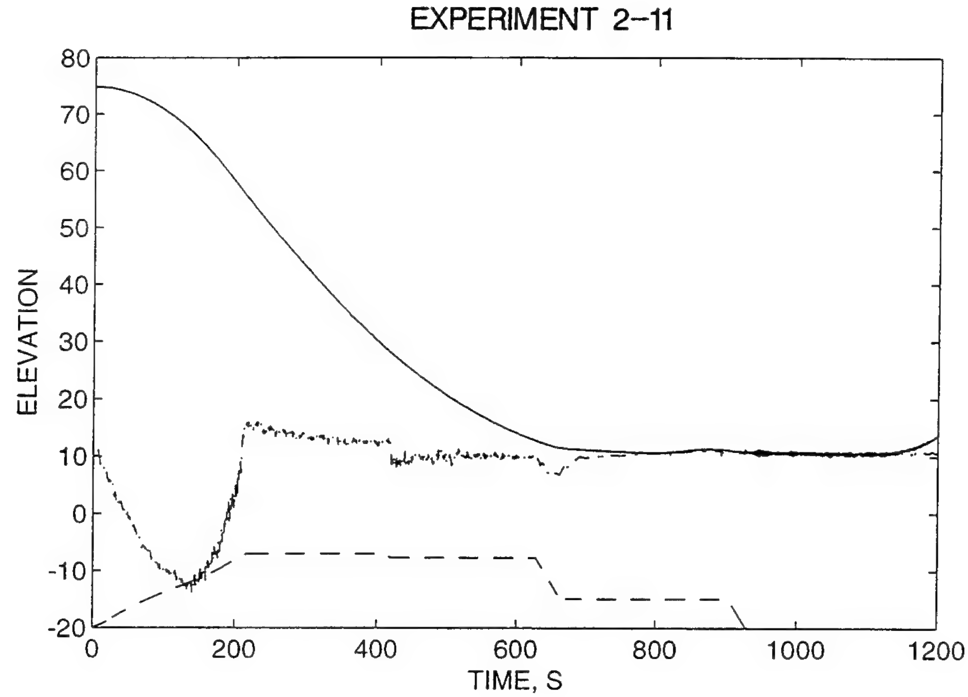
- —— LOCK WATER SURFACE
- · — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- · · · · VALVE WELL WATER SURFACE
- — — VALVE OPENING

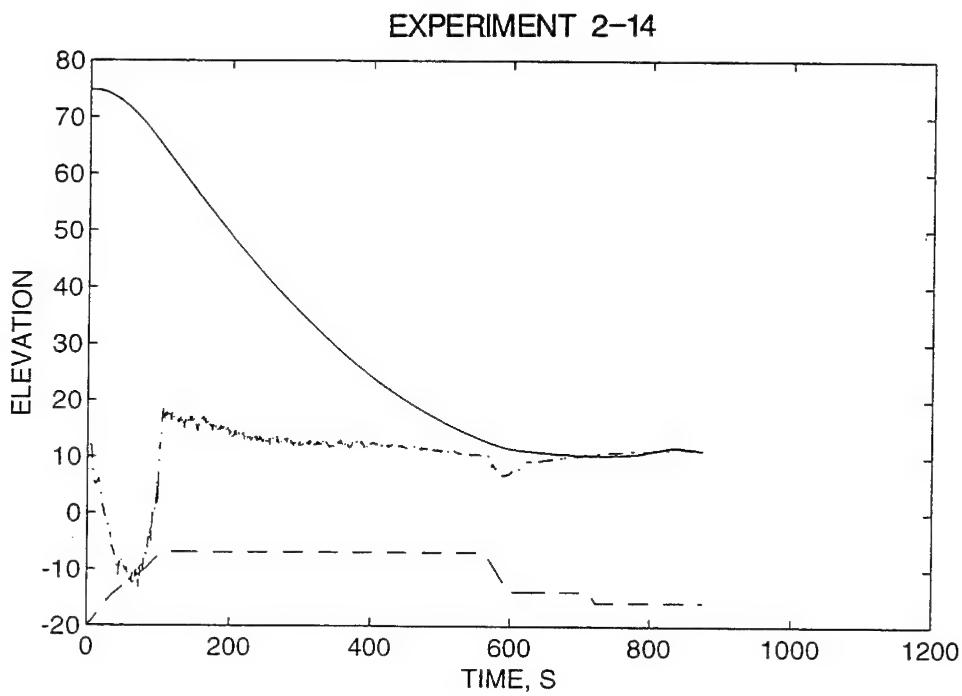
WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

TWO-VALVE FILLING OPERATION

SEPTEMBER 1993

EXPERIMENTS 2-12 AND 2-15





LEGEND

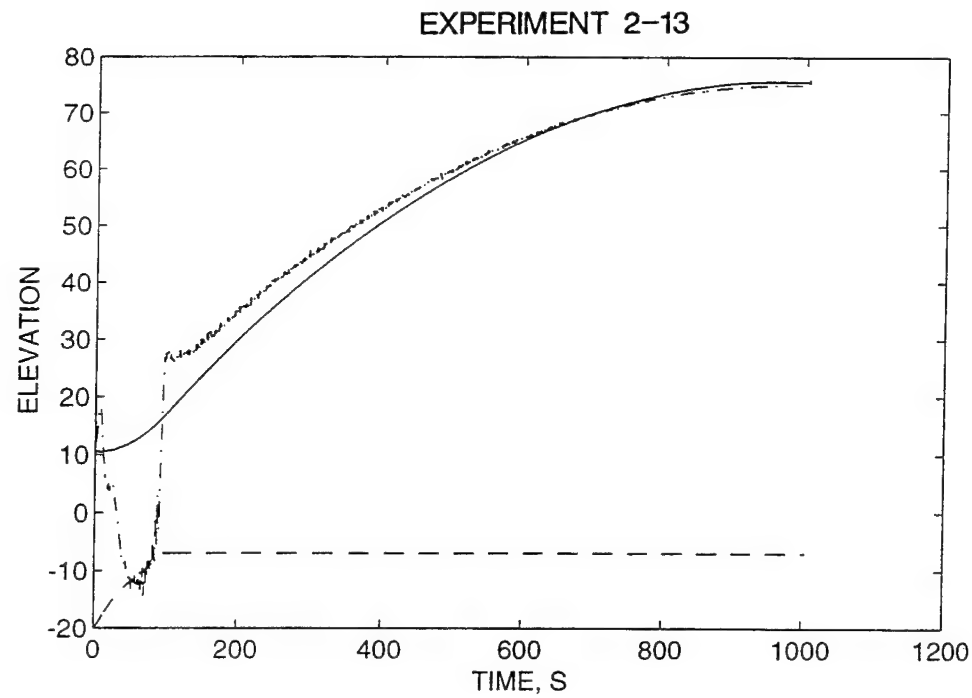
- LOCK WATER SURFACE
- PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- VALVE WELL WATER SURFACE
- VALVE OPENING

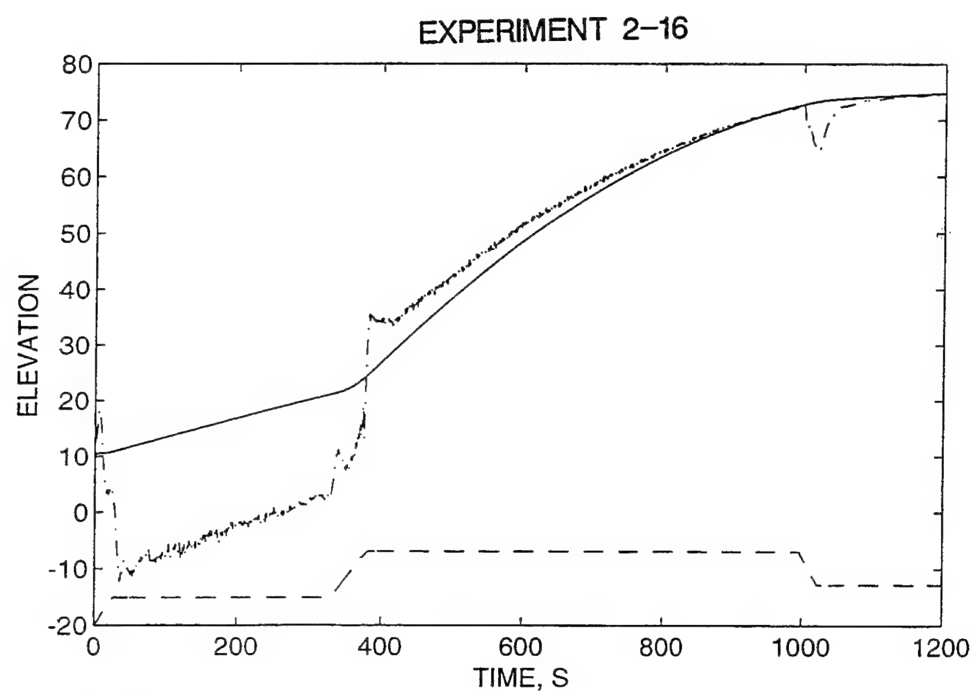
WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

TWO-VALVE EMPTYING OPERATION

SEPTEMBER 1993

EXPERIMENTS 2-11 AND 2-14





LEGEND

—— LOCK WATER SURFACE

· — · PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE

· · · · VALVE WELL WATER SURFACE

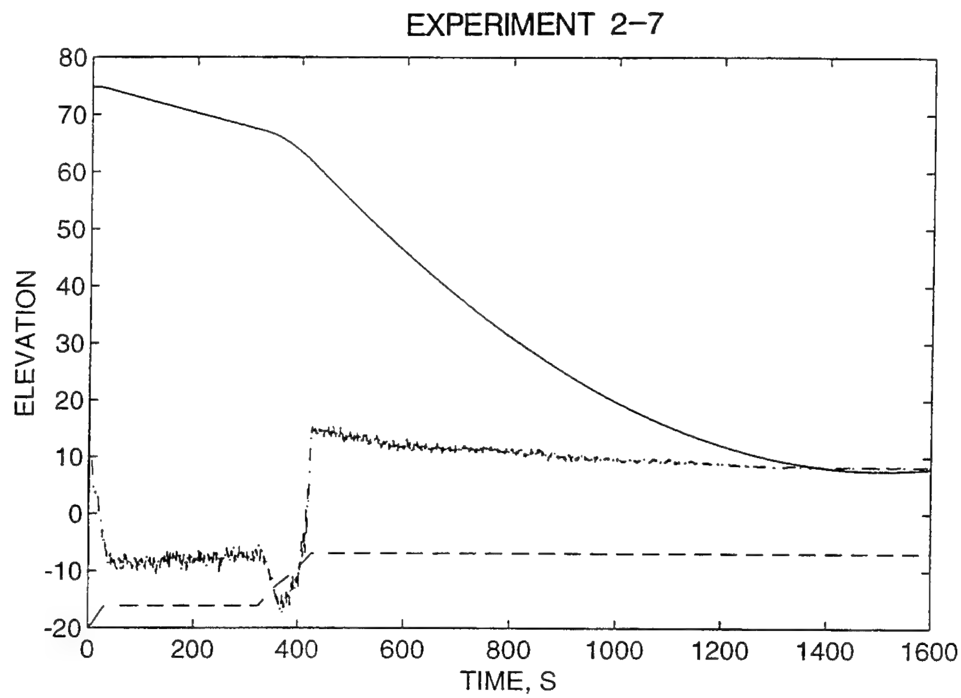
— — VALVE OPENING

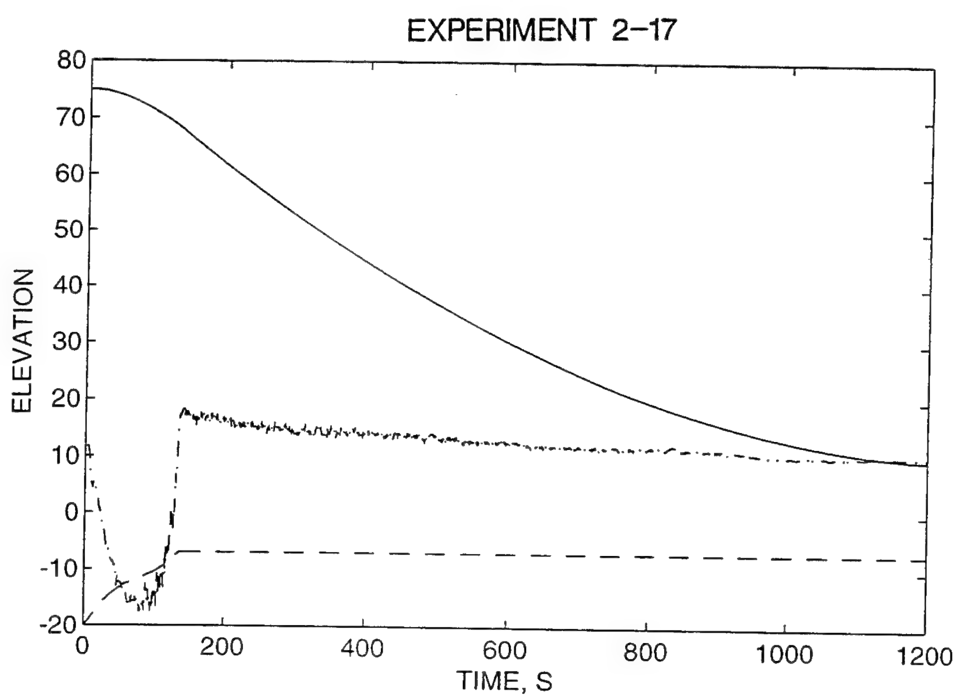
WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

ONE-VALVE FILLING OPERATION

SEPTEMBER 1993

EXPERIMENTS 2-13 AND 2-16





LEGEND

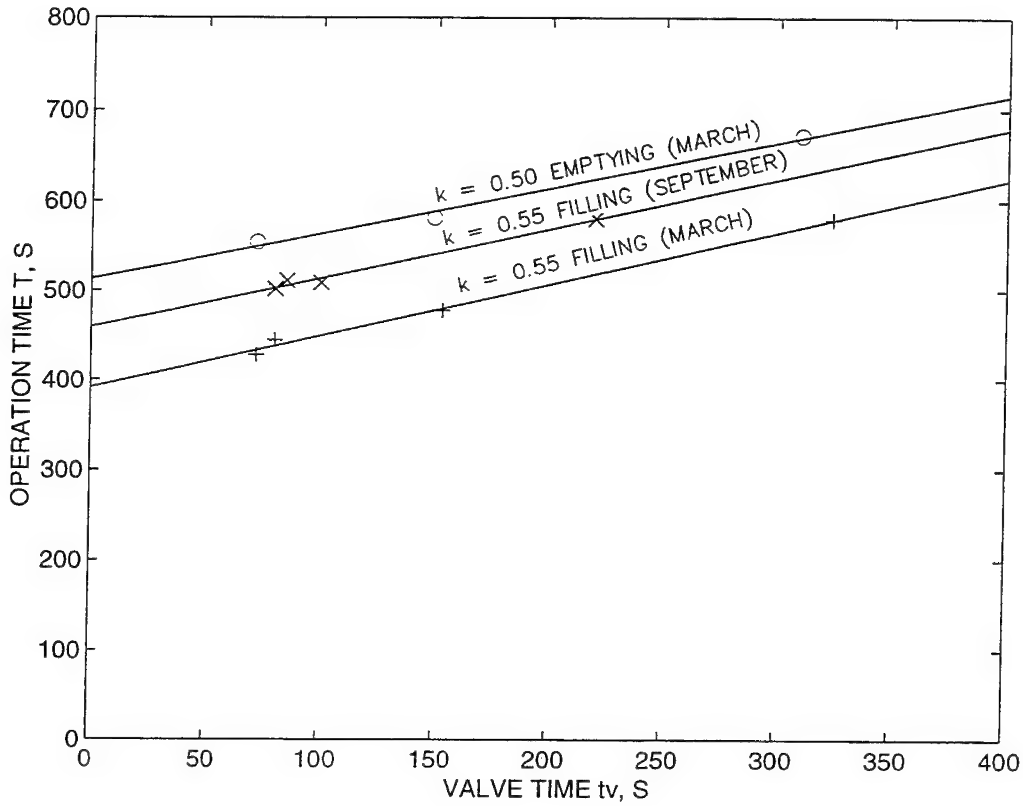
- LOCK WATER SURFACE
- PIEZOMETRIC HEAD DOWNSTREAM OF TAINTER VALVE
- VALVE WELL WATER SURFACE
- VALVE OPENING

WATER-SURFACE ELEVATIONS AND CULVERT PRESSURES

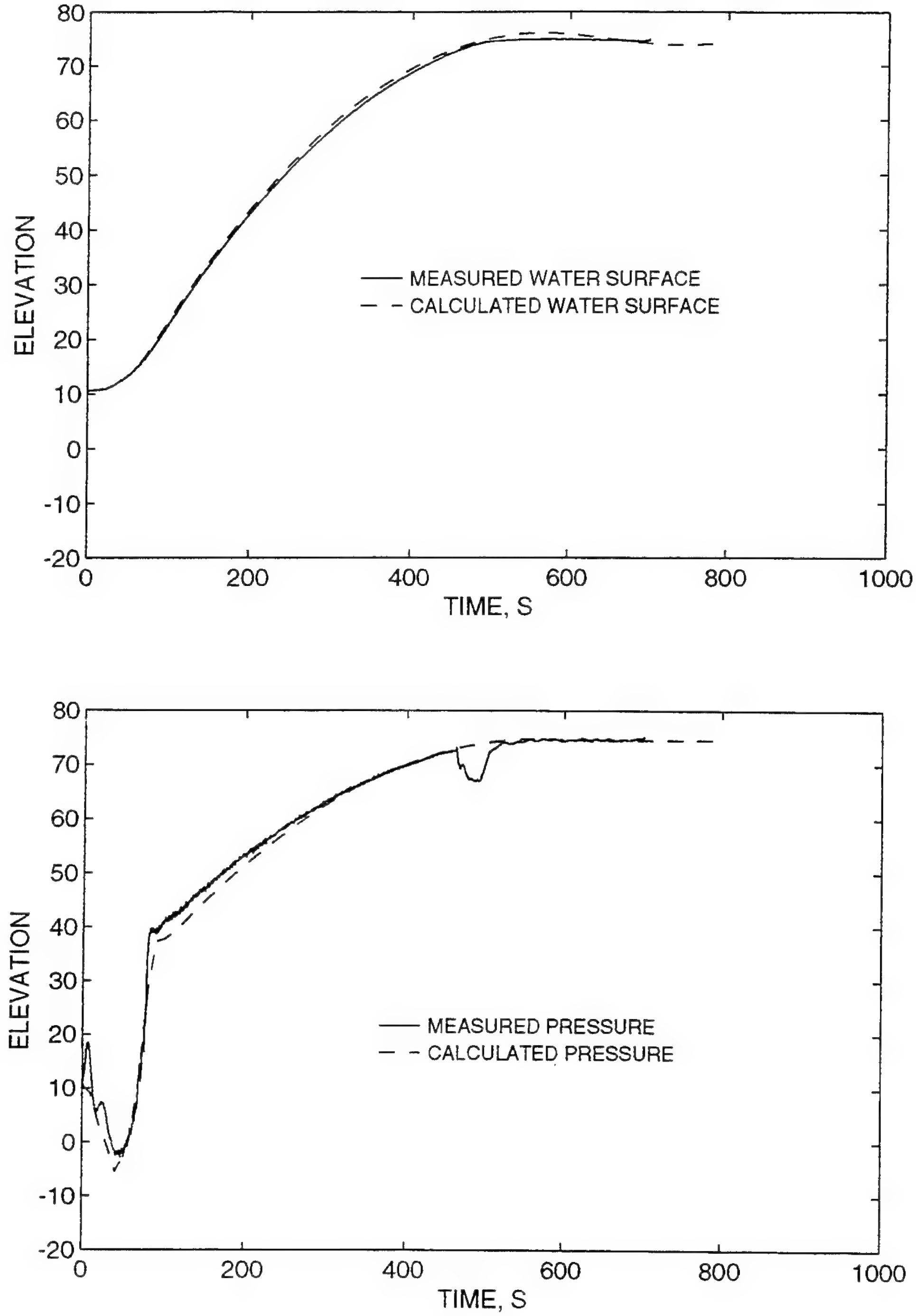
ONE-VALVE EMPTYING OPERATION

SEPTEMBER 1993

EXPERIMENTS 2-7 AND 2-17



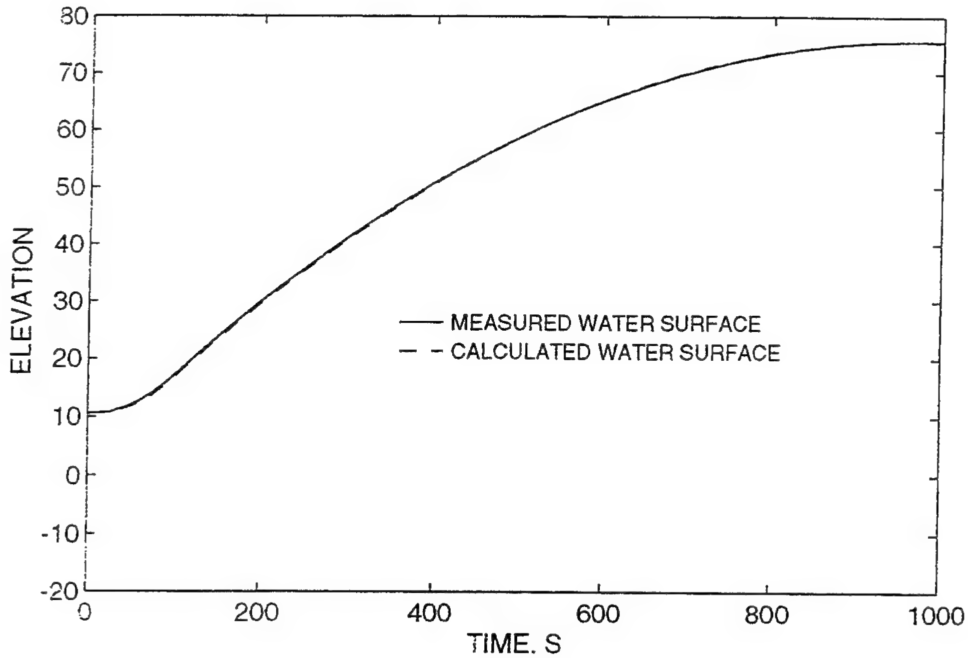
VALVE COEFFICIENTS, k
MARCH AND SEPTEMBER EXPERIMENTS

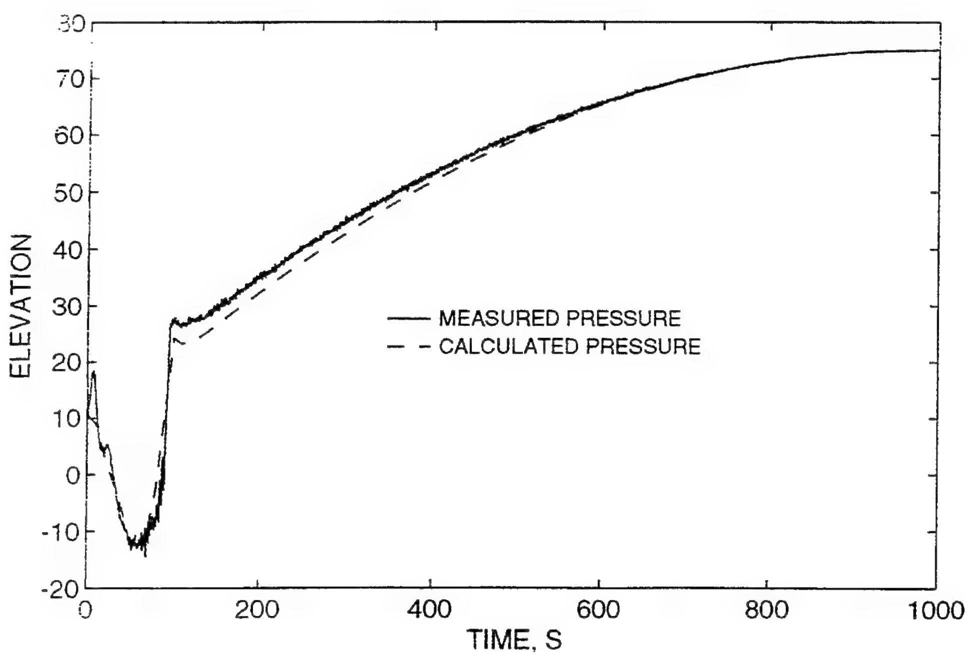


MODEL - PROTOTYPE COMPARISON OF LOCK WATER SURFACE AND PRESSURE BELOW VALVE

TWO-VALVE FILLING OPERATION

EXPERIMENT 2-12

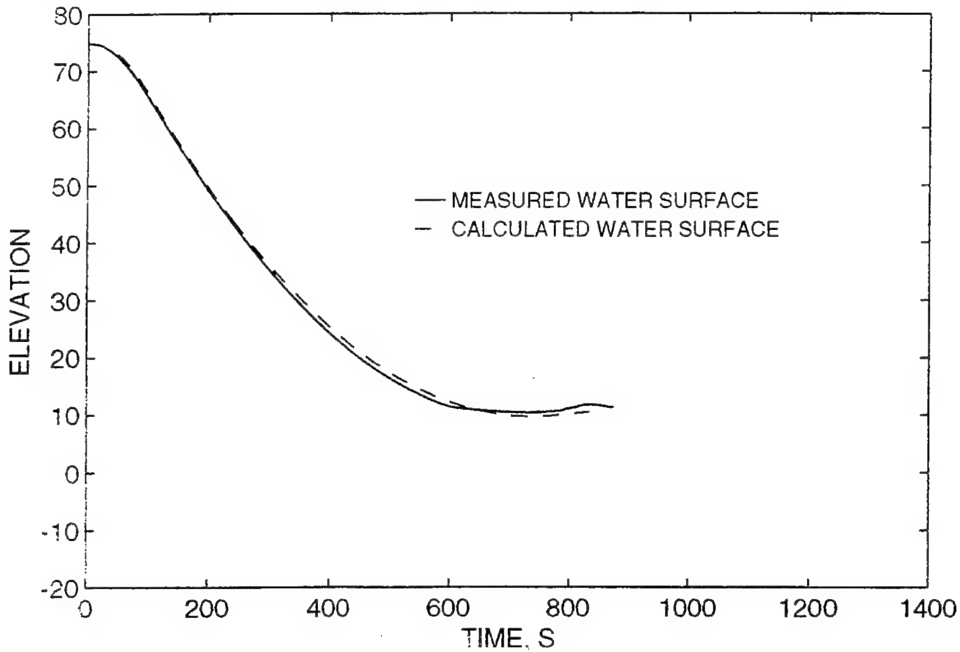


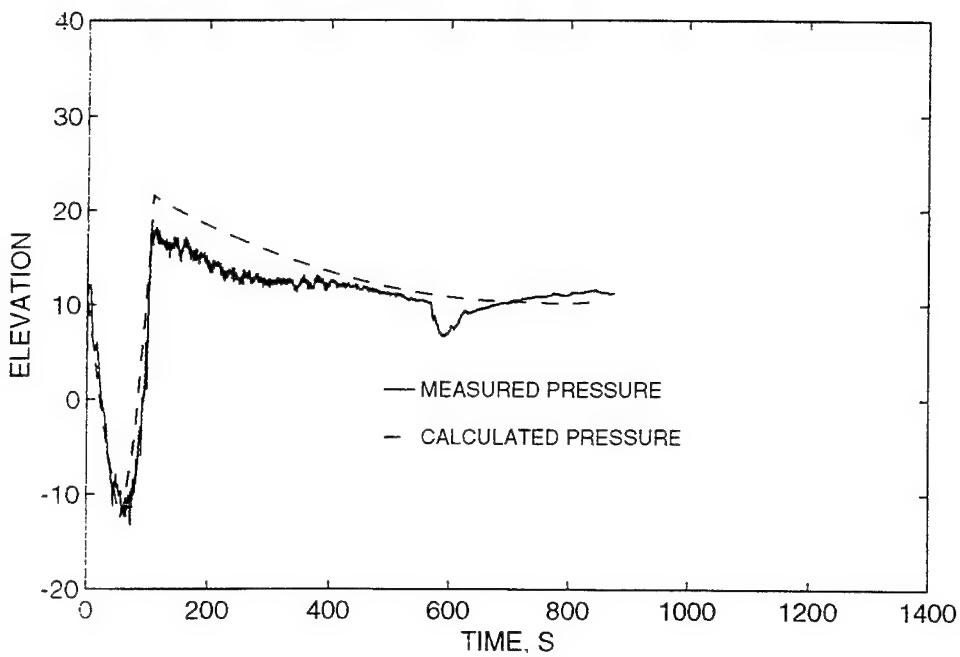


MODEL - PROTOTYPE COMPARISON OF LOCK WATER SURFACE AND PRESSURE BELOW VALVE

ONE-VALVE FILLING OPERATION

EXPERIMENT 2-13

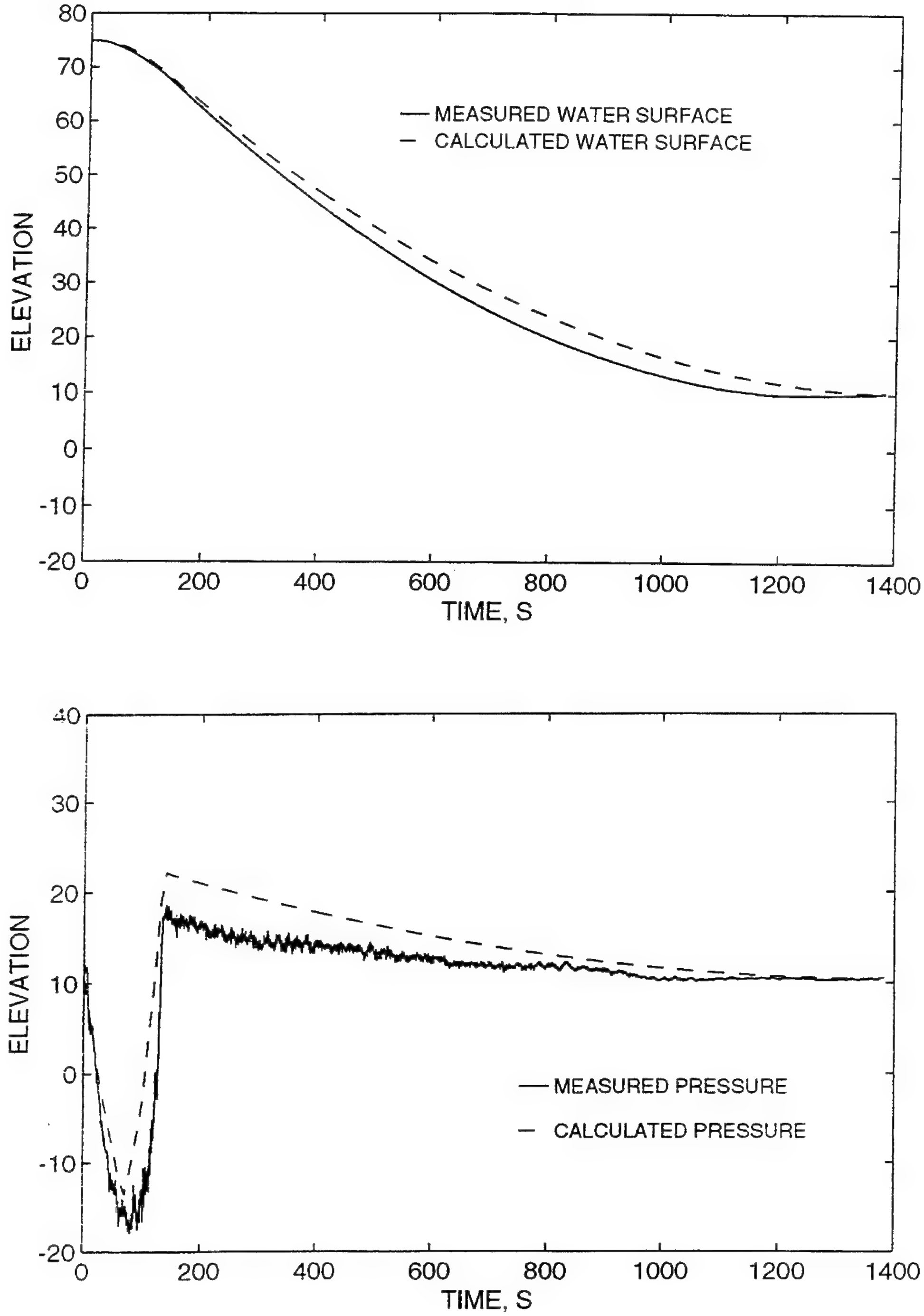




MODEL - PROTOTYPE COMPARISON OF LOCK WATER SURFACE AND PRESSURE BELOW VALVE

TWO-VALVE EMPTYING OPERATION

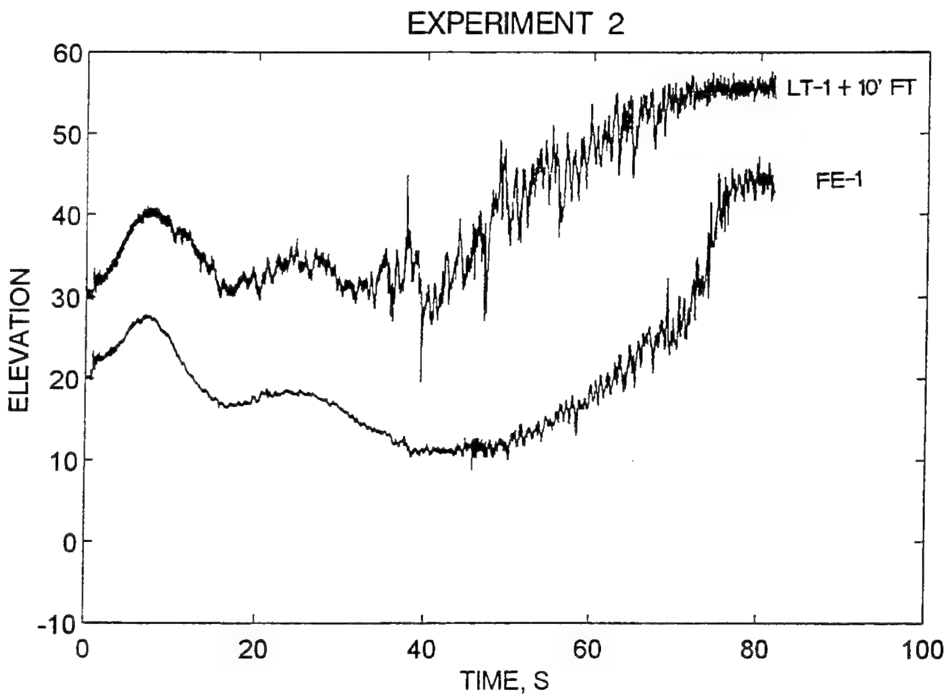
EXPERIMENT 2-14

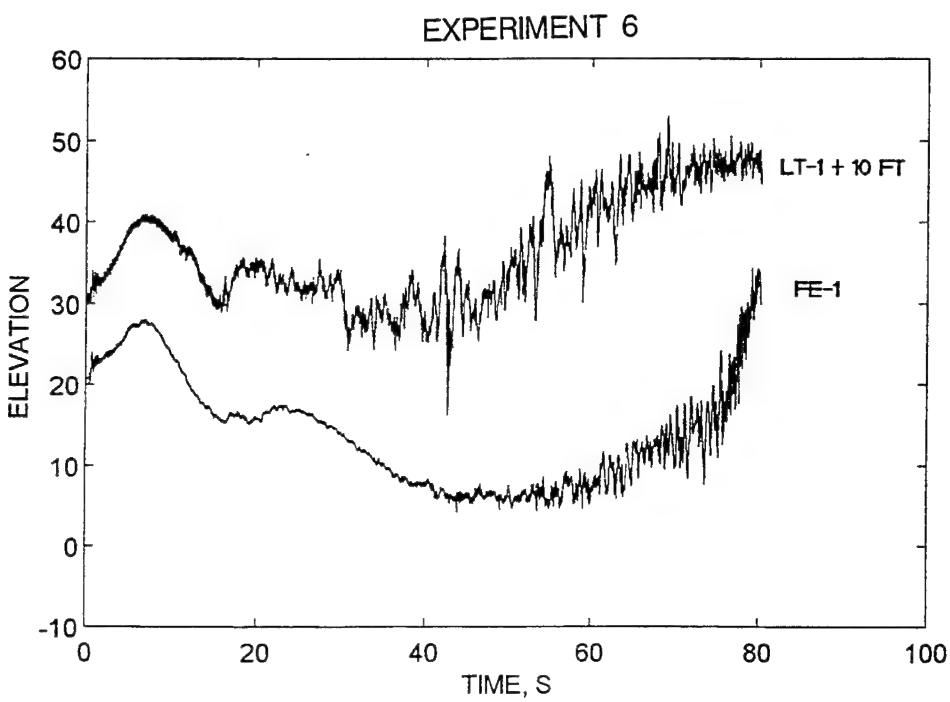


MODEL - PROTOTYPE COMPARISON OF LOCK WATER SURFACE AND PRESSURE BELOW VALVE

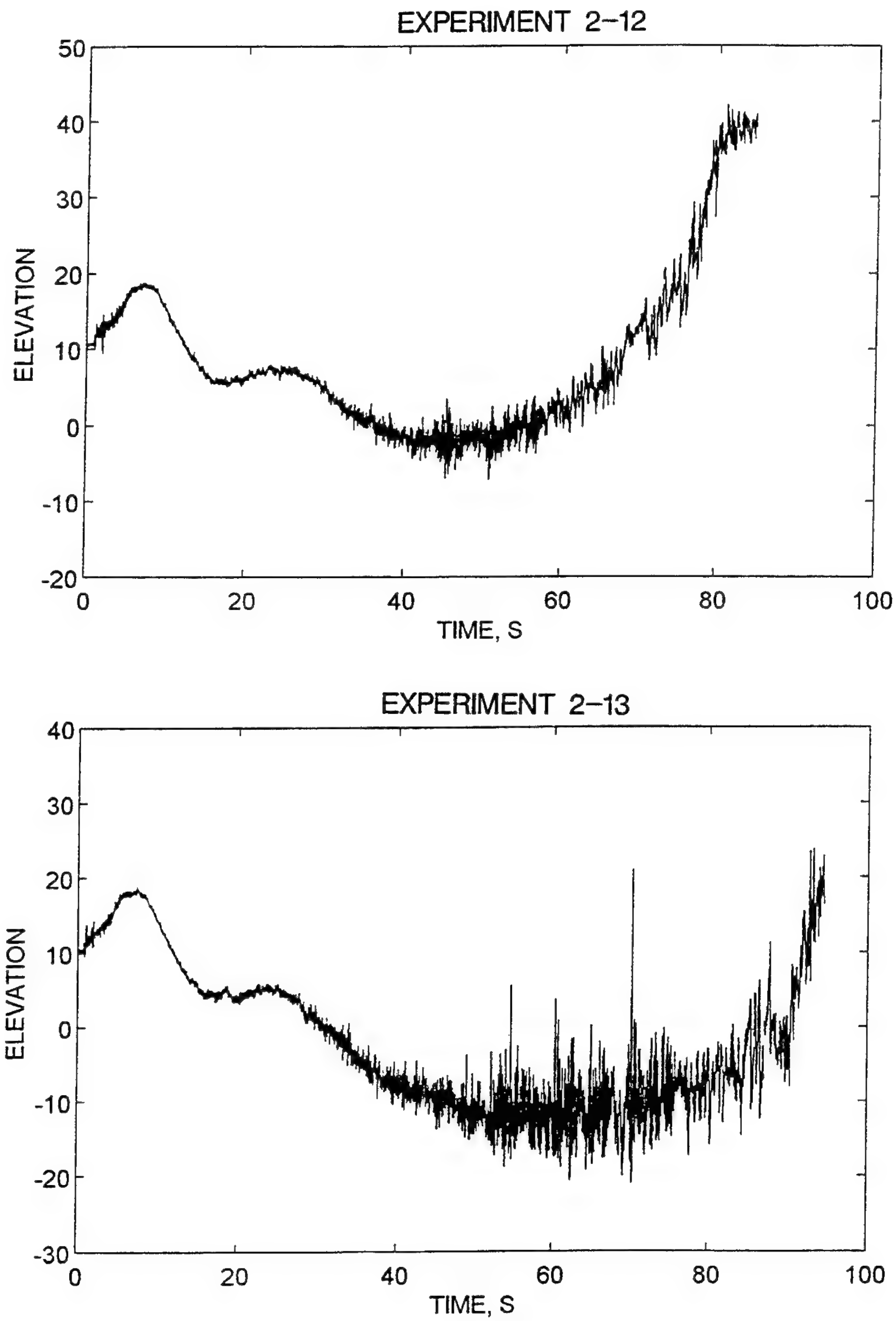
ONE-VALVE EMPTYING OPERATION

EXPERIMENT 2-17

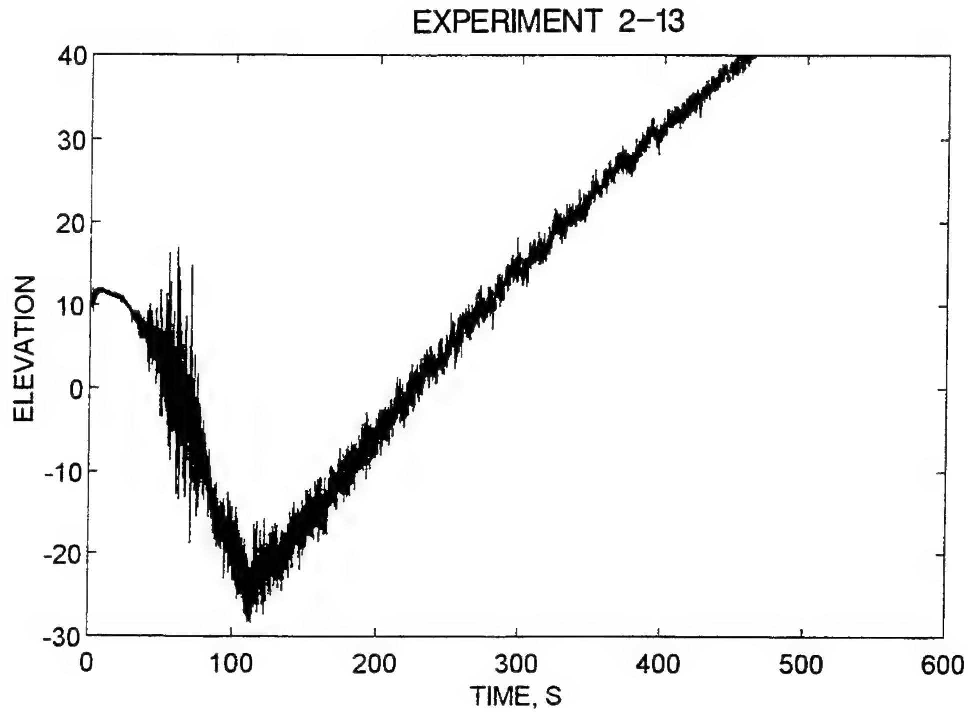




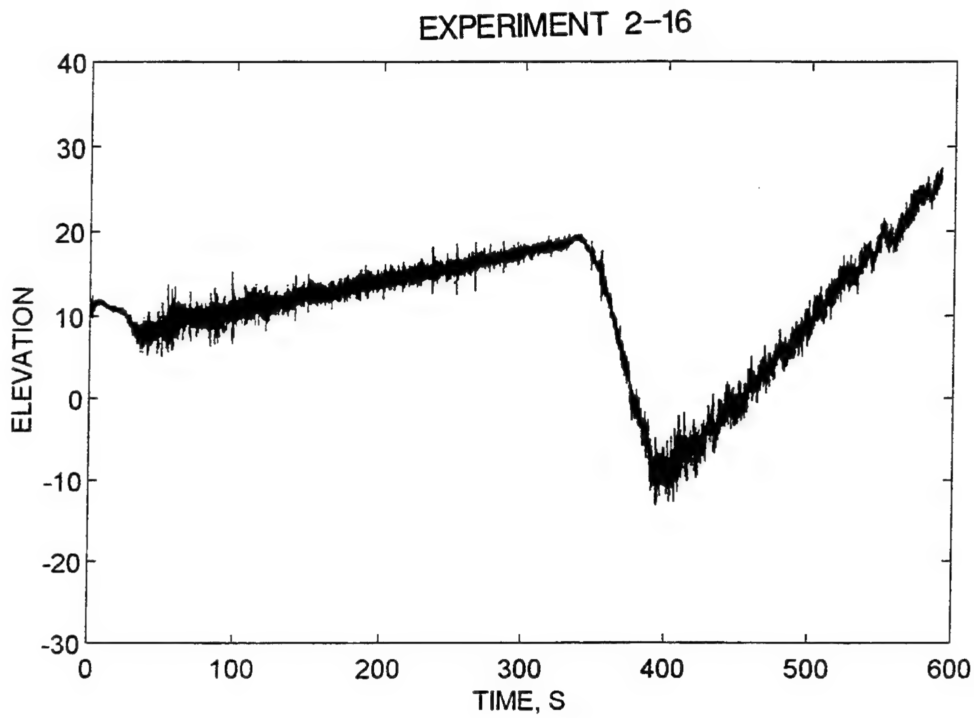
CULVERT PIEZOMETRIC PRESSURES BELOW
TAINTER VALVE (FE-1) AND IN CULVERT (LT-1)
EXPERIMENT 2, TWO-VALVE FILLING OPERATION
EXPERIMENT 6, ONE-VALVE FILLING OPERATION
MARCH 1993



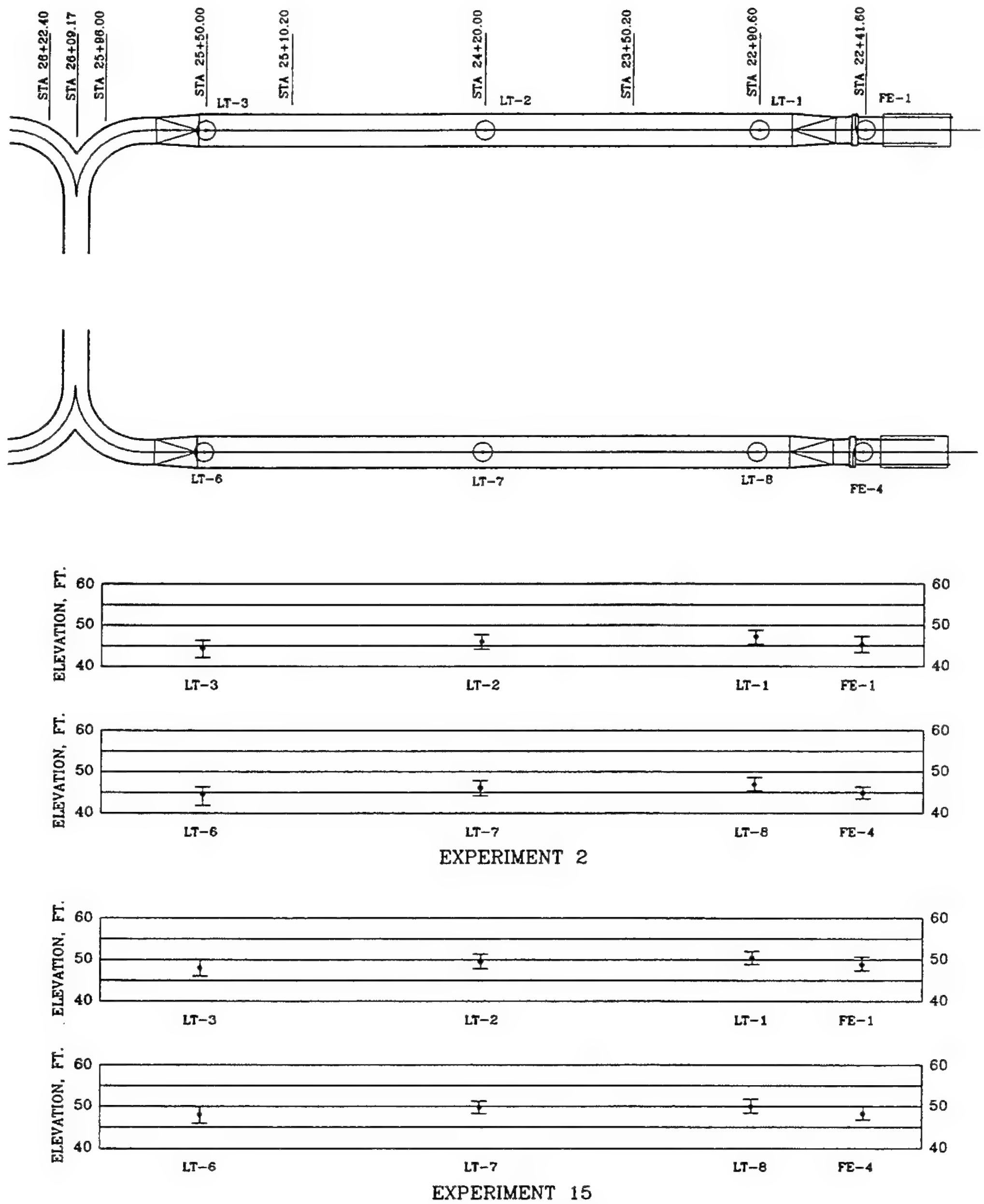
CULVERT PIEZOMETRIC PRESSURES
BELOW TAINTER VALVE (FE-1)
EXPERIMENT 2-12, TWO-VALVE FILLING OPERATION
EXPERIMENT 2-13, ONE-VALVE FILLING OPERATION
SEPTEMBER 1993



PIEZOMETRIC PRESSURES
IN CROSSOVER AREA (FE-5)
ONE-VALVE FILLING OPERATION
EXPERIMENT 2-13, 96 SECOND VALVE TIME
SEPTEMBER 1993

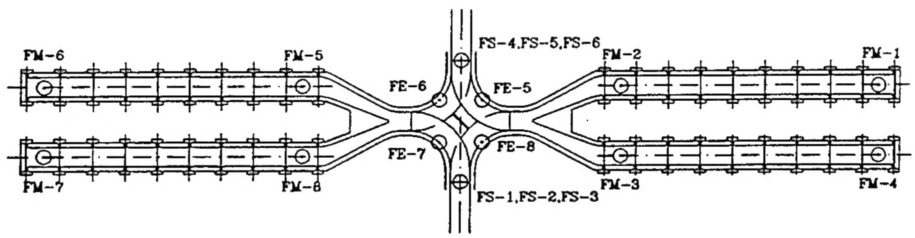


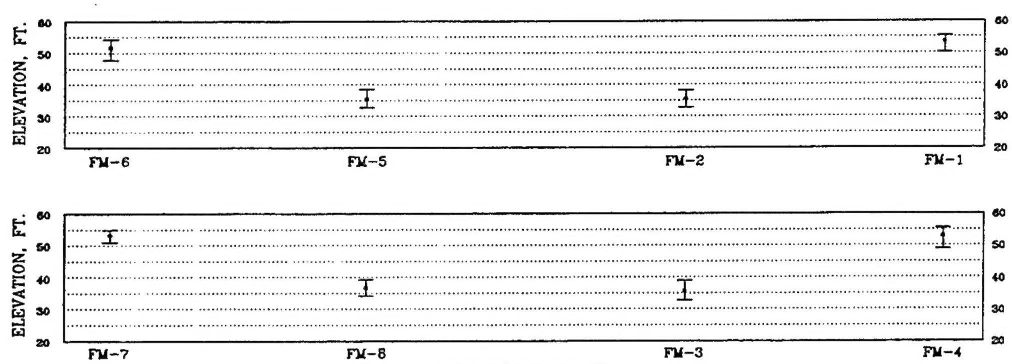
PIEZOMETRIC PRESSURES
IN CROSSOVER AREA (FE-5)
ONE-VALVE FILLING OPERATION
EXPERIMENT 2-16, STEPPED VALVE OPERATION
SEPTEMBER 1993



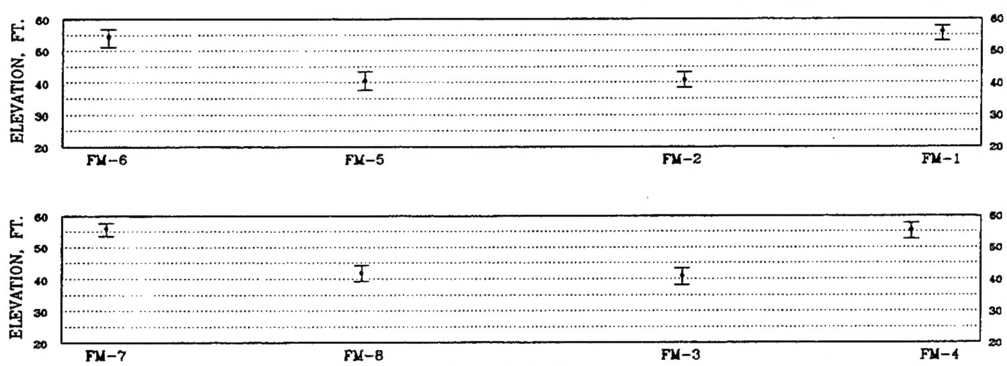
LOCK FILLING CULVERTS
BALANCE OF FLOW

MAXIMUM, MINIMUM, AND MEAN PIEZOMETRIC PRESSURES
DURING 30-SECOND MAXIMUM FLOW PERIOD





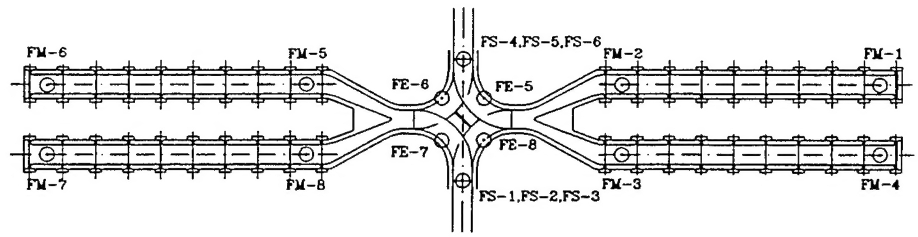
EXPERIMENT 2

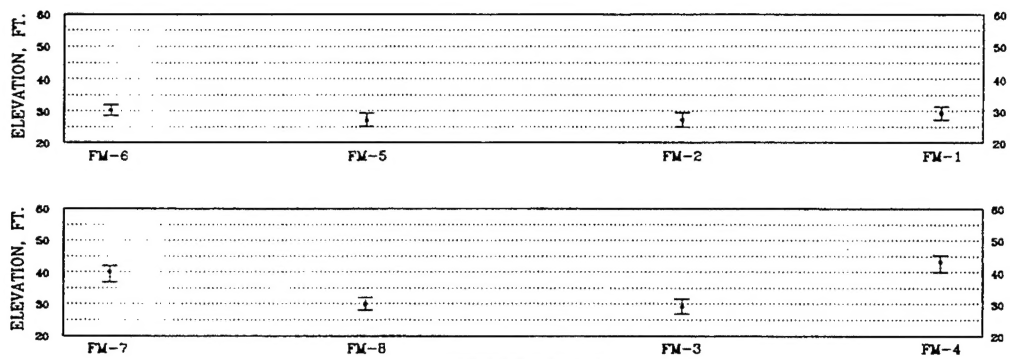


EXPERIMENT 15

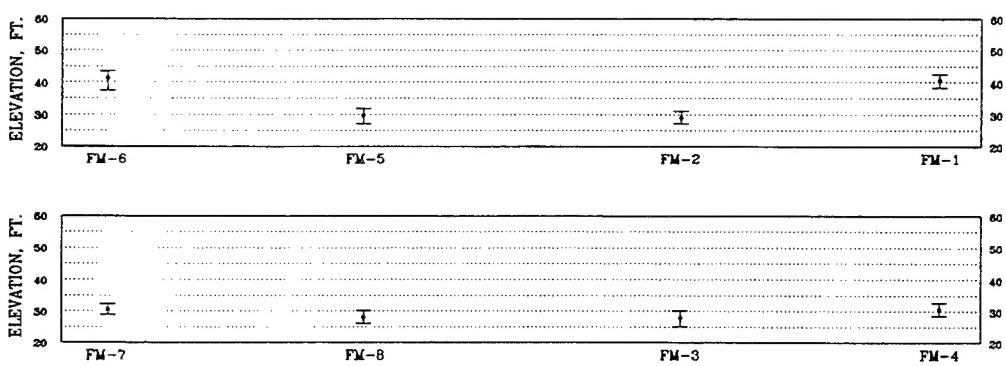
LOCK FLOOR MANIFOLD
BALANCE OF FLOW
TWO-VALVE EXPERIMENTS

MAXIMUM, MINIMUM, AND MEAN PIEZOMETRIC PRESSURES
DURING 30-SECOND MAXIMUM FLOW PERIOD





EXPERIMENT 6



EXPERIMENT 10

LOCK FLOOR MANIFOLD
BALANCE OF FLOW
ONE-VALVE TESTS

MAXIMUM, MINIMUM, AND MEAN PIEZOMETRIC PRESSURES
DURING 30-SECOND MAXIMUM FLOW PERIOD

REPORT DOCUMENTATION PAGE

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A prototype evaluation was conducted on the new navigation lock at the Bonneville Project in March 1993, immediately after the lock was completed. Additional prototype investigations were made in September 1993 during a period of low tailwater. The lock, which is located on the Columbia River 42 miles east of Portland, OR, was evaluated to determine its operating characteristics and hydraulic efficiency. The results also evaluated the accuracy of both physical and analytical model predictions.

Prototype measurements included pressures in the culvert system, valve movements, and upstream, downstream, and lock chamber water surface elevations. A system of 34 flush-mounted pressure transducers was installed in the lock culverts during construction. Additional pressure transducers and potentiometers were installed and connected to recording equipment prior to data acquisition.

Results indicated that the lock functioned as designed during normal (two-valve) filling and emptying operations. Pressures in the lock filling culverts and the floor manifolds showed that the flow was balanced between opposite sides of the lock. The prototype evaluation also determined that the lock was more efficient for the single-valve operations than model results had predicted.

(Continued)

14. SUBJECT TERMS
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Locks (waterways)
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Prototype evaluation

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16. PRICE CODE

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13. ABSTRACT (Concluded).

Pressures below atmospheric were measured under extreme conditions but were above allowable thresholds. Because of low pressures, a stepped-valve operation should be used for single-valve filling and emptying operations. The stepped-valve operation will minimize low pressures and eliminate the potential for cavitation at the tainter valves and in the crossover region.